The impact of anxiety on perceptual-motor behaviour

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Chapter 1

Introduction and overview

Introduction

> "A mountaineer is smoothly climbing one of the classical rock routes in the Alps. She uses the available grips and irregularities of the rock and places her feet onto the sometimes-small protrusions. Approaching a key passage in the route she hesitates and pays close attention to the opportunities before continuing. She assesses which possibilities the surface of the rock offers: Is it, for example, possible to cling onto the tiny hole at the right in order to reach the small edge a bit further away or is that edge then unreachable? How stable is that edge? Tension increases. She judges the alternative possibilities, weighing their pros and cons against each other. After some hesitation she chooses the tiny hole at the right. A few moments later she has passed the difficult passage."[1]

This quote contains the key elements of the present thesis: human motor performance, anxiety, perceiving and realizing action possibilities, and attention. The work reported in the thesis seeks to further the understanding of the impact of anxiety on human motor performance. Human motor performance can be studied in different ways and at different levels (e.g., Michaels & Beek, 1995). The level of analysis adopted in the present thesis is that of human action. Studying movement at this level implies that human motor performance is considered a relational activity, that is, an activity whereby the environment supports several possibilities for behaviour (affordances, Gibson, 1979) of which the actor realizes the one(s) that is (are) most appropriate at a given moment. For instance, the situation on a soccer pitch offers a soccer player the possibilities to pass, shoot, or dribble. Depending on the concrete situation in the game (e.g., where the ball is, where other players are), the broader context of the game (e.g., the score at that moment, the relevance of the game), and the intentions, traits and characteristics of the player (e.g., technical ability, game insight, anxiety, fatigue, ambition), the player eventually realizes one of the affordances of the situation: he or she passes, shoots, or dribbles. In realizing affordances it is possible that more than one affordance is perceived while only one can be realized. It is, for example, impossible to both shoot at goal and pass at the same time. Only the eventual action reveals what the selection has been.

The present thesis aims to understand how factors such as anxiety and fatigue co-determine which affordances are being perceived and realized (cf. Bakker, Oudejans, & Pijpers, 1999). With respect to an analysis of the factors that determine the perception and realization of affordances, Newell's (1986) classification of 'constraints on action' into three categories is useful. Constraints can be considered limiting factors, that is, factors restricting the (number

[1] This was the lead of an article on anxiety and climbing we once submitted. "I liked the evocative opening" one of the reviewers wrote, "I hope no one manages to convince you to sterilize it". However, we realized that in the remainder of the article we failed to live up to expectations and we decided to drastically rewrite the paper and to remove the quote. Nevertheless, it seems fully appropriate to use the quote as an opening statement for this thesis as a whole.

of) possible actions. The length of a basketball player, for instance, limits (in combination with other factors) the affordances of this athlete on the court, such the ability to dunk the ball. Newell distinguishes organismic, environmental, and task constraints. Organismic constraints are the limiting factors of the actor himself, such as length, jumping power, maximal running speed, but also factors such as motivation, anxiety, fatigue, and will power. Environmental constraints could, in principle, contain all limiting factors outside the actor. According to Newell, however, it is useful “to distinguish between environmental constraints that are general and those that are task specific. Environmental constraints and task constraints are not mutually exclusive as their definition depends on the nature of the task” (p. 350). Examples of environmental constraints are gravity, temperature of the environment, humidity, and illumination. In addition, information sources in the environment that are available to the perceiver in a certain situation (so that he or she can catch the ball; e.g., vertical optical acceleration and time-to-contact information) can be considered environmental constraints. Examples of task constraints are the rules of a game in sports, which stringently determine what is and is not possible (allowed) during the game.

The theme of this thesis fits well with the tradition of ecological psychology (Gibson, 1979) as well as the study of human action and movement from that perspective (Michaels & Beek, 1995). In particular, Chapters 4 and 5 report studies on the perception and realization of affordances. Therefore, in the remainder of this introductory chapter, I will first provide an outline of the ecological approach focusing on the key concept of affordance. This concept has been, and continues to be, the topic of much debate. To provide the reader with insight into some of the issues at stake, parts of this discussion will be highlighted briefly. Furthermore, because this thesis focuses more on organismic state variables, especially anxiety, than has been the case in ecological psychology, I will also review the existing literature on the anxiety-performance relationship. While this literature is vast, the mechanisms underlying this relationship are still poorly understood (Janelle, 2002; Mullen, Hardy, & Tattersall, 2005). Finally, in the last section of this *Introduction and overview*, the contents of the present thesis will be outlined.

Ecological psychology and affordances

Ecological psychology (cf. Gibson, 1966, 1979) was developed as an alternative to the cognitive approaches that dominated psychology during the second half of the twentieth century. At that time (as today), most perception theories were based on the assumption that actors perceive their environment indirectly, via mental representations (e.g., Reed, 1988; Withagen, 2004), that is to say, objects and events have no inherent meaning, implying that their meaning must be created internally and stored by the actor (Jones, 2003): thus, perception is indirect.[2] Gibson (1966, 1979), however, asserted that the stimulus information available to the actor is rich, not impoverished, and he developed an interactionist view of perception and action (Greeno, 1994).[3] Objects and events have inherent meaning, which is detected and exploited by the actor without mental calculation: perception is direct. Gibson sought to understand how perception could inform the actor about the meanings of environmental objects (Jones, 2003). For this purpose he introduced the concept of *affordance*. As Gibson (1979) put it: "The theory of affordances implies that to see things is to see how to get about among them and what to do or not to do with them" (p. 223).

After the introduction of the concept in 1966 (Gibson, 1966) and its gradual development in the years thereafter, Gibson defined affordances in 1979 as follows:

> The *affordances* of the environment are what it *offers* the animal, what it *provides* or *furnishes*, either for good or ill. The verb to *afford* is found in the dictionary, but the noun *affordance* is not. I have made it up. I mean by it something that refers to both the environment and the animal in a way that no existing term does. It implies the complementarity of the animal and the environment. (p. 127)[4]

As the concept of affordances was still evolving during his life and was unfinished by the time of his death in 1979, Gibson never fully explicated what he meant by perceiving things with reference to an animal (Jones, 2003), which has led to much debate in ecological psychology (e.g., Heft, 1989; Jones, 2003; Michaels, 2003; Stoffregen, 2000, 2003).

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[2] In addition, most of the psychology of perception was about phenomena that occur when an observer is stationary, which in Gibson's view overlooks some of the crucial characteristics of what it claims to be about (Greeno, 1994).

[3] Greeno (1994) argued that Gibson's view of perception has been difficult to understand for many cognitive scientists because "Gibson's reasoning involves some quite general framing assumptions about activity and cognition that differ from those of mainstream cognitive science" (p. 337). The concept of information was at the centre of scientific research of the mainstream of cognitive science—that is, how is information constructed by people and animals. Gibson (1966, 1979) focused on the information that is available in the environment to guide the activities of humans and other animals. This theoretical shift does not imply a denial of individual cognition as a theoretically important process.

Gibson's revolutionary ideas, and especially the concept of affordance, sometimes led to irritated, (but also understandable) reactions:

> I [Don Norman] was quietly lurking in the background of a CHI-Web discussion, when I lost all reason: I just couldn't take it anymore. "I put an affordance there," a participant would say, "I wonder if the object affords clicking." "Affordances this, affordances that. And no data, just opinion. Yikes!"

Norman continues with "I originally hated the idea [of affordances]: it didn't make sense. I cared about processing mechanisms, and Gibson waved them off as irrelevant." (see http://www.jnd.org/dn.mss/affordances-interactions.html) Yet, Norman has embraced the concept of affordance and applied it successfully in the field of (industrial) design (e.g., Norman, 1988).

[4] Stoffregen (2003) wondered what kinds of things are afforded: "The answer is that *behaviors* are afforded. (…) if a stair is a certain proportion of a person's leg length, it affords climbing..." (p. 116, italics added)

Turvey (1992) was one of the first who attempted to formalize the concept of affordance, also to encourage the systematic development of this key ecological notion. Turvey's point of departure was that, in order to be successful, actions must be controlled prospectively. Prospective control requires that the behavioural possibilities of surface layouts and events be perceived. To understand prospective control in realist terms, it is needed to establish "that possibilities for action are real or factual states of affairs (i.e., they exist independently of perceiving or conception) that are perceived directly" (p. 174). This is in accordance with Gibson's (1979) claim that affordances are not simply phenomenal quantities of subjective experience. Affordances are real properties of the environment relative to the animal; they are real properties that imply the complementarity of an animal and its surroundings. Turvey (1992) detailed what counts as a property at the ecological scale as follows: "There are only propertied things; neither properties nor individual things are real independently of one another" (p. 176). Consequently, Turvey argued that a description of affordances should be in terms of substantial properties[5] rather than attributes.

Disposition is the common term for a property of a thing that is potential, latent, or possible. Turvey (1992) argued that dispositional properties are fundamental to affordances. He identified the ontological character of an affordance as follows: (a) an affordance is a real possibility; (b) an affordance is a disposition; and (c) an affordance is complemented with a so-called *effectivity*, that is, "a specific combination of the functions of its tissues and organs taken with reference to an environment" (Shaw, Turvey, & Mace, 1982, p. 197). Whereas an affordance is a disposition of a particular surface layout, "an effectivity is the complementing disposition of a particular animal" (Turvey, 1992, p. 179). So, an action is the actualisation of these paired dispositions.

Turvey (1992) set the stage for the further experimental and theoretical study of the concept of affordance[6] and inspired Stoffregen, one of his former students, to reflect on and critique Turvey's definition of affordance, in particular his claim that affordances are properties of the environment (Stoffregen, 2003). Stoffregen argued that Turvey did not define affordances as properties of the animal-environment system. As the ecological approach to perception and action is a systems approach to behaviour, the unit of analysis is the animal-environment system (Gibson, 1979; Lombardo, 1987). Therefore, the concept of affordance should be explicitly positioned at the level of the animal-environment system, rather than its component parts as is done by Turvey (1992) by treating affordances as

[5] "A substantial property is a feature that some substantial individual possesses and does so whether one is aware of it. By contrast, an attribute or predicate is a feature one assigns to some object. In other words, an attribute or predicate is a concept, an epistemological entity without clear ontological status." (Turvey, 1992, p. 176)

[6] For further discussion about the (definitions of) affordances, the reader is referred to the collection of papers that appeared in *Ecological Psychology*: Chemero, 2003; Heft, 2003; Jones, 2003; Michaels, 2003; Stoffregen, 2003.

properties of the environment. Component parts of systems have properties as well as the system itself. However, as Stoffregen (2003) argued, the properties of the parts and the properties of the system may differ qualitatively as can be illustrated with a triangle (the system) and the lines that it comprises (the component parts of the system). The lines have properties, such as length and width. The triangle also has properties such as triangularity. However, the properties of the triangle differ qualitatively from the properties of the lines. Similarly, according to Stoffregen (2003), affordances are (emergent) properties of the animal-environment system that are qualitatively different from the properties of its component parts (animal and environment).

Grounding the definition of affordance in terms of dispositional properties, as Turvey (1992) asserted, is in Stoffregen's view also problematic, especially Turvey's notion that dispositions occur in pairs. If an affordance is a disposition, Stoffregen (2003) continued, then there must be a corresponding disposition that is something else—that is, not an affordance. Consequently, Turvey was forced to identify another entity, not a property of the environment, that can serve as the 'other' disposition, complementary to the affordance, and which he found in the notion of effectivity (Stoffregen, 2003). Stoffregen argued that dispositions have additional properties that make them in his opinion unfit for use in defining affordances. Dispositions are tendencies rather than actualities, and when dispositions become real, they are said to be actualised. Because many actions are possible in a given situation, the great majority of them are not actualised, which is in contradiction with Turvey's (1992, p. 179) claim that "Dispositionals never fail to be actualized when conjoined with suitable circumstances. Disposition and suitable circumstance equals actuality" (p. 178). Thus, as Stoffregen (2003) concluded, Turvey's definition of affordances cannot account for the actualisation of any given affordance when multiple affordances exist, which is always the case, and, consequently, affordances cannot be dispositional properties.

The preceding discussion illustrates that there is a considerable divergence of opinion on what is exactly meant by affordance despite its avowed centrality in the ecological approach to perception and action (Michaels, 2003; Stoffregen, 2000, 2003). The debate on affordances is unresolved and still ongoing.[7] Most important for the current thesis, it concerns an ontological discussion leaving the relevance of the epistemological questions addressed in this thesis unaffected. Irrespective of one's particular position in the discussion, within an ecological

[7] Several authors have offered their refinements or formalizations of Gibson's affordance concept (e.g., Chemero, 2003; Heft, 2003; Michaels, 2003) that in some instances are qualitatively different from each other. See also for instance Kirlik (2004) who criticised Stoffregen's (2003) definition of affordance suggesting that it is too broad; Kirlik even doubted whether this definition could play a fruitful role in the advancement of ecological psychology as a scientific discipline. A reaction on this critique can be found in Stoffregen (2004).

framework it is important to identify and understand how properties of the animal-environment system constitute opportunities for action. How do properties of the environment and of the animal affect perception and action? This question is also central in the studies on the perception of affordances that have been performed under the rubric of ecological psychology over the last two decades.

Affordance studies

If an actor is perceiving affordances while being engaged in a particular activity, he or she must be capable of perceiving the relation between environmental properties and the properties of his or her own action system. By implication, actions are ‘body-scaled’ (e.g., Warren, 1984, 1988). For example, to successfully reach for objects, people must scale the distance of the object in terms of their effective reach actions, which are constrained by geometric measures (e.g., arm length, leg length; see, e.g., Carello, Grosofsky, Reichel, Solomon, & Turvey, 1989; Mark, 1987; Mark et al., 1997; Warren, 1984, 1988). Initial research on affordances was focused on these ‘invariable’ intrinsic *anthropometric* body measures such as leg length (Warren, 1984), or arm length (Carello et al., 1989). Konczak, Meeuwsen, and Cress (1992), however, emphasized that action capabilities are not exclusively defined by anthropometrics, but that most perceptual-motor tasks are also subject to additional biomechanical constraints such as strength, limb mobility, and joint flexibility. They demonstrated that the perception of affordances (judgement of climbability of stairs) needs to be related to observers’ action capabilities, or, in Turvey’s (1992) terminology, effectivities (see also Cesari, Formenti, & Olivato, 2003; Oudejans, Michaels, Bakker, & Dolné, 1996; Oudejans, Michaels, van Dort, & Frissen, 1996; Pepping & Li, 2000). Despite these developments, experimental inquiry into affordances and prospective control has identified the animal’s body and its linear dimensions as the reference frame (e.g., Mark, 1987; Pufall & Dunbar, 1992; Warren, 1984), which might be taken to suggest that only biomechanical and kinematic properties of animals play a role in affordances and their perception. However, as Stoffregen (2003, p. 125) remarked:

> Any property of an animal can bear a relation to some property of the environment that gives rise to an affordance, including biomechanical properties, such as leg length and other types of properties, such as strength and flexibility (…), *skills*, *beliefs*, and *emotional states*. [italics added]

Thus far, ecological psychologists have given little attention to emotional (cognitive and affective) factors in the study of perceiving and realizing affordances although, as Stoffregen (2003) suggests, there is ample reason to assume that emotional states also play a role. Therefore, the current thesis focuses on the role of state variables—especially anxiety—on perceiving, selecting and realizing affordances. Given the paucity of research into this area within ecological psychology, it might seem strange to adopt this particular theoretical framework for studying the relation between anxiety and perceptual-motor behaviour. However, as I will venture to do in the following, this choice can be motivated from a critical review of the vast literature on the anxiety-performance relationship in sport psychology and corresponding theoretical models and methods of investigation. To anticipate, it will be argued that work in this area has been largely dominated by product-oriented approaches where more process-oriented approaches would be required, and that ecological psychology offers a conceptual framework for pursuing the latter kind of approach in the domain of interest.

Anxiety and performance

The anxiety-performance relationship has been studied extensively and is one of the most widely investigated and debated areas in sport psychology (e.g., Woodman & Hardy, 2001). A number of models have been put forward to describe and explain the relationship between anxiety and performance, such as the inverted-U hypothesis (e.g., Yerkes & Dodson, 1908; Woodman & Hardy, 2001), the drive theory of Hull and Spence (Hull, 1943; Spence & Spence, 1966), Apter's 'reversal theory' (Apter, 1982; Kerr, 1997), Hanin's 'individualized zone of optimal functioning (IZOF) hypothesis' (Hanin, 1989, 2000), the multidimensional models (Martens, Vealey, & Burton, 1990), and the cusp catastrophe model (Hardy, 1990, 1996).[8] Following Jones (1995a), and based on three major conceptual approaches that have been adopted in anxiety-performance research, this section is divided into subsections dealing with general arousal-based approaches, general anxiety-based approaches, and multidimensional anxiety-based approaches.

General arousal-based approaches

Research on the anxiety-performance relationship has struggled with conceptual and methodological dilemmas concerning the identification of the anxiety-performance relationship, and the examination of the anxiety response itself (Jones, 1995a). Until quite recently, the literature on the anxiety-performance relationship has been dominated by "general arousal-based explanations" (ibid.) such as the drive theory and the inverted-U hypothesis. Drive theory was originally proposed by Hull (1943) and later modified and extended to complex behaviour by Spence and Spence (1966). It posits that increases in drive (often used synonymously with arousal, stress, and anxiety) are associated with a linear

[8] Several excellent overviews of theories on anxiety and performance are available in the literature (e.g., Cox, 2002; Gould, Greenleaf, & Krane, 2002; Hackfort & Schwenkmezger, 1993; Janelle, 2002; Jones, 1995; Landers & Boutcher, 1998; Raglin, 1992; Raglin & Hanin, 2000; Weinberg, 1989, 1990; Woodman & Hardy, 2001).

increase or decrease in performance, depending on the dominant response. When the dominant response is incorrect—often in the early stages of learning—increases in arousal will impair performance; when the dominant response is correct—later in learning when the task is well learned—increases in arousal will enhance performance. However, to the extent that empirical support is available (Neiss, 1988), drive theory only appears to pertain to extremely simple tasks, not to complex tasks, and is thus not apt to explain human motor performance (e.g., Martens, 1971; Weinberg, 1979).

The inverted-U hypothesis—or the Yerkes-Dodson Law as it originated from the early work of Yerkes and Dodson (1908)—proposes that the relationship between anxiety will be in the form of a symmetrical inverted-U, such that increases in anxiety will result in increases in performance up to a certain point, beyond which further increases in anxiety will result in a gradual decrement in performance (Jones, 1995a; Martens, 1971). Hence, for every type of behaviour there exists an optimal level of arousal that produces maximal performance (Jones, 1995a). The experimental support for the inverted-U hypothesis for human motor performance is limited (e.g., Landers, 1994; Neiss, 1988), and most studies have proposed the inverted-U hypothesis as a *post hoc* explanation of previously obtained results (Martens, 1971).

A rather different general arousal-based approach (Jones, 1995a) is reversal theory (Apter, 1982). Reversal theory is as much a theory of personality as it is a theory of arousal (Cox, 2002). It is based on the concept of metamotivational states.[9] In particular, it postulates that there are four possible pairs of metamotivational states[10] of which the telic-paratelic state has received the most attention in the context of human motor performance (Woodman & Hardy, 2001). Individuals are described as being either telic—that is, as having a goal-directed orientation toward life—or paratelic—that is, as having a 'here-and-now' orientation (Cox, 2002). Reversal theory proposes that an individual's orientation can (suddenly) switch back and forth ('reverse') between those orientations. When in a telic state, individuals prefer low arousal and will interpret high arousal as anxiety, whereas in a paratelic state, they prefer high arousal and will experience high arousal as excitement (Kerr, 1990; 1997). This perceived pleasure is known as 'hedonic tone'. One's hedonic tone can be either pleasant (i.e., perceiving a low level of arousal as relaxation and a high level of arousal as excitement) or unpleasant (i.e., perceiving a low level of arousal as boredom and a high level of arousal as anxiety). Note that an individual seeks to increase the hedonic tone, not to increase or

[9] Metamotivational states "…are 'frames of mind' which determine certain general phenomenological characteristics of motivation at a given time; they are about the way in which the individual interprets his own motives" (Apter, 1982, p. 39). The states are called *metamotivational* as they only determine something *about* motivation.

[10] These are telic-paratelic, negativism-conformity, autic-alloic, and sympathy-mastery (Apter, 1982; Kerr, 1990). It is beyond the scope of this *Introduction and overview* to elaborate on these metamotivational states.

decrease arousal. However, as there does not appear to be an obvious theoretical reason for proposing that pleasant feelings about one's level of arousal should lead to better performance (Woodman & Hardy, 2001), reversal theory does not seem to offer a great deal in terms of explaining how and why anxiety might affect human motor performance.

Drive theory, the inverted-U hypothesis and to a lesser extent reversal theory are based upon unidimensional conceptualisations of arousal and anxiety. As a result of dissatisfaction with this conceptual limitation, researchers reverted to Spielberger's (1966) state-trait approach (Jones, 1995a).

General anxiety-based approaches

Spielberger (1966) argued that for a theory of anxiety to be adequate, it must differentiate between anxiety as a mood state and as a personality trait. His state-trait theory of anxiety differentiates between state anxiety and trait anxiety, where the former is defined as an emotional state "characterized by subjective, consciously perceived feelings of apprehension and tension, accompanied by or associated with activation or arousal of the autonomic nervous system" (p. 17), and the latter—trait anxiety—is defined as "a motive or acquired behavioral disposition that predisposes an individual to perceive a wide range of objectively nondangerous circumstances as threatening and to respond to this with state anxiety reactions disproportionate in intensity to the magnitude of the objective danger" (p. 17).

Anxiety typically has been measured with self-report questionnaires, such as the State-Trait Anxiety Inventory (STAI) (Spielberger, Gorsuch, & Luchenne, 1970). Often the state version of the STAI was used as a measure of a generalized, undifferentiated anxiety state leading to the conclusion that both high and low levels of state anxiety interfere with performance (Spielberger, 1989). This notion of optimal anxiety states strongly resembles that of optimal arousal theory (inverted-U hypothesis), and it is often difficult to distinguish the two (Jones, 1995a).

Hanin's (1980, 1989, 2000; Raglin & Hanin, 2000) zone of optimal functioning (ZOF) hypothesis represents further work on optimal anxiety states.[11] It questions the basic assumption of the inverted-U hypothesis that a moderate level of anxiety (arousal) results in best performance. Hanin states that an individual's best performance occurs within a zone of optimal state anxiety, which differs across individuals. This individual-specific bandwidth of anxiety can be identified via repeated observations of his or her performance levels and associated anxiety levels. As such, Hanin's theory emphasizes within-subject variation and makes relatively precise predications about anxiety levels at which optimum performance is likely to occur (Jones, 1995a), thus providing a practical tool for helping athletes determine

[11] In later works, the ZOF hypothesis is labelled as 'individualized zones of optimal functioning', or IZOF (Gould, Greenleaf, & Krane, 2002).

their optimal levels of anxiety.

Limitations of the ZOF-hypothesis include (a) the absence of an explanation of the processes involved in the anxiety-performance relationship (Jones, 1995a), and (b) the unidimensional rather than multidimensional conceptualisation of anxiety, even though Gould, Tuffey, Hardy, and Lochbaum (1993) and Woodman, Albinson, and Hardy (1997) examined ZOFs by using a sport-specific multidimensional state anxiety measure. Whether the ZOF-hypothesis provides a viable theory for explaining the anxiety-performance relationship remains unclear. For instance, Turner and Raglin (1996) found support for the theory, whereas Randle and Weinberg (1997) failed to find support, and others only found partial (Prapavessis & Grove, 1991; Woodman et al. 1997), or weak support (Russell & Cox, 2000).

Multidimensional anxiety-based approaches

The multidimensional models (Martens et al., 1990) and the cusp catastrophe model (Hardy, 1990, 1996) of anxiety and performance arose from dissatisfaction with existing explanations of the anxiety-performance relationship that was based on a predominantly unitary conceptualisation of anxiety. Researchers saw more promise in a multidimensional conceptualisation of anxiety and they acknowledged that anxiety has at least two dimensions—that is, cognitive anxiety and somatic anxiety. This distinction was introduced by Borkovec (1976) and Davidson and Schwartz (1976), building on the earlier distinction of Liebert and Morris (1967) between the emotionality and worry components of anxiety. Cognitive anxiety can be defined as "negative expectations and cognitive concerns about oneself, the situation at hand, and potential consequences" (Morris, Davids, & Hutchings, 1981, p. 541). Somatic anxiety can be conceptualised as the perception of one's bodily symptoms of automatic reactivity such as butterflies in the stomach, sweating, shakiness, increased heart rate, and tense muscles (Davidson & Schwartz, 1976; Martens et al., 1990).

The multidimensional conceptualisation of anxiety culminated in the development of the Competitive State Anxiety Inventory-2 (CSAI-2)[12] (Martens, Burton, Vealey, Bump, &

[12] The Competitive State Anxiety Inventory (CSAI) is a sport-specific anxiety scale, which was developed by Martens, Burton, Rivkin, and Simon (1980). It is a modified version of the Spielberger State Anxiety Inventory. As the CSAI is insensitive to separate cognitive and somatic anxiety, Martens et al. (1982, 1990) developed the CSAI-**2**, which measures both cognitive and somatic anxiety in the sports context. Although the CSAI-2 was originally designed to measure the cognitive and somatic components of (competitive) state anxiety, during the development of the questionnaire a third factor emerged, which was later identified as 'self-confidence'. Self-confidence may be conceptualised as one's belief in meeting the challenge of the task to be performed; it is a realistic expectation about achieving success (Martens, 1987). Since the mid-1980s of the twentieth century, the CSAI-2 has been the most used tool in the sport psychological field of research (e.g., Cerin, Szabo, Hunt, & Williams, 2000). See for a critical discussion of the CSAI-2, Jones and Uphill (2004) and Lane, Sewell, Terry, Bartram, and Nesti (1999).

Smith, 1990), which has figured prominently in anxiety research. Although the separation of anxiety into cognitive and somatic components has been subject to criticism (e.g., Landers, 1994), a body of literature has supported the usefulness of distinguishing cognitive and somatic anxiety components (Jones, 1995a). In the sport psychological literature, the notion that anxiety has both cognitive and somatic components is referred to as multidimensional anxiety theory (Martens et al., 1990).

In multidimensional anxiety theory a series of two-dimensional relationships between cognitive anxiety, somatic anxiety, self-confidence (see also Footnote 12) and performance are proposed: Cognitive anxiety is supposed to have a negative linear relationship with performance; somatic anxiety is supposed to have an inverted-U shaped relationship with performance, and self-confidence is supposed to have a positive linear relationship with performance (Woodman & Hardy, 2001). Burton (1988) provided support for these three predictions, however, a number of other studies provided weak or, at best, moderate support for the CSAI-2 predictions (Burton, 1998; Raglin, 1992; Woodman & Hardy, 2001).

Multidimensional anxiety theory attempts to explain the potentially complex four-dimensional relationships among cognitive anxiety, somatic anxiety, self-confidence, and performance in a series of *independent* two-dimensional relationships. Hardy (1990; Hardy & Parfitt, 1991) identified this as one of the major shortcomings of multidimensional anxiety theory. In their view, the anxiety components must work together in some interactive way to affect performance. As a result of their dissatisfaction with extant explanations of anxiety-performance relationships, they developed and proposed the cusp catastrophe model of anxiety and performance. The cusp catastrophe model attempts to describe the effects of anxiety upon performance in terms of an interaction between self-confidence, cognitive anxiety, and the body's physiological response to anxiety (Hardy, 1990, 1996; Jones & Hardy, 1989), providing elegant predictions regarding anxiety-performance relationships. Probably because of the complexity of the model, a number of issues need to be addressed before it can be designated as the model of anxiety and performance. For a recent critical elaboration and empirical investigation of the cusp catastrophe model, the reader is referred to Cohen, Pargman, and Tenenbaum (2003).[13]

Preview

New conceptions of anxiety were instrumental in the further clarification of the relationship between anxiety and performance. In particular, the anxiety concept was refined so as to include not only the intensity of the anxiety state, but also the frequency of the anxiety reactions (e.g., Swain & Jones, 1993), as well as the direction of the anxiety as perceived by

[13] See also and Tenenbaum and Becker (2005), and Woodman and Hardy (2005).

the performer (e.g., Jones, Swain, & Hardy, 1993; Swain & Jones, 1996).

Despite these developments, theorizing in anxiety research remains hampered by the absence of consistent experimental findings regarding the effect of anxiety on human motor performance (Jones, 1995a; Kleine, 1990). One of the reasons for this state of affairs is probably the prevalence of product-oriented approaches in pertinent research, which, by definition, ignore that the effect of anxiety on performance is mediated by a wide variety of processes. To better understand this mediation, and thus to help disentangle the multifaceted relationship between anxiety and performance, this thesis systematically investigated the effects of anxiety on perceptual-motor behaviour, or as mentioned earlier, on perceiving, selecting and realizing affordances. Pursuing, in so doing, an ecological-psychological approach the anxiety-performance relationship is studied at the level of human action and a process-oriented rather than a product-oriented approach is adopted. In addition, the traditional definition of anxiety is adopted, that is, one "that refers to the construct as a negative, cognitive and perceived physiological response to uncertain appraisals of coping with the demands of a stressful situation (e.g., competition)" (Hanton, Mellalieu, & Hall, 2004, p. 480).

At the outset it was important to find an adequate and expedient way to manipulate anxiety, and it was anticipated that climbing on a climbing wall would provide a good context for achieving that goal (see also Chapters 2-4). Anxiety was manipulated in novice climbers by asking them to perform a climbing task low on the wall—thus creating a low-anxiety condition—and the 'same' task higher on the wall—corresponding to a high-anxiety condition. Hence, the research reported in the present thesis is not about climbing behaviour as such, but it exploits climbing behaviour as a suitable experimental paradigm to gain further insight into the anxiety-performance relationship in human motor performance.

To better understand the intricate relationship between anxiety and performance, a process-oriented rather than a product-oriented approach was adopted in Chapters 2 and 3. The studies in question were conducted in order to identify the effects of anxiety on physiological, psychological, and behavioural processes underwriting task performance, rather than task performance per se (Chapter 2). Chapter 3 focuses on the changes in movement execution to gain further insight into the relations between anxiety, performance, and movement behaviour. Chapters 2 and 3 are closely related and demonstrate both that a process-oriented approach may help to disentangle the anxiety-performance relationship.

As a consequence of the adopted process-oriented approach, one is almost inevitably confronted with the largely neglected role of perceptual processes in the literature on anxiety and performance. Taking Gibson's (1979) ecological psychology as a starting point, in Chapter 4 three experiments are reported on the relationship between anxiety and perception in the context of climbing (Chapter 4). The results seemed to indicate that anxiety plays a role in the selection of action possibilities as afforded by the environment. Chapter 5 reports an attempt to generalize the conclusions of Chapter 4 regarding the relationship between anxiety and perception to another state variable—namely fatigue. Manipulating that state variable offers more possibilities to induce extreme changes in mood state than manipulating the state variable anxiety (which for humanitarian and ethical reasons has its limitations), and, thus, to change participants' action capabilities (for reaching) to a considerable larger magnitude.

Chapter 6 (Epilogue) summarizes and highlights the implications of the thesis' main experimental findings for theory development about the relationship between state variables such as anxiety and fatigue and perceptual-motor behaviour. The upshot of this discussion is that 'states' like anxiety and fatigue affect a plenitude of physiological, subjective, perceptual and motor processes that contribute differentially, and probably interactively, to the resulting performance. Consequently, it is impossible to provide an encompassing theoretical account for the relationship between anxiety and performance without addressing the complexity of these mediating processes.

Chapter 2

Anxiety-performance relationships in climbing: A process-oriented approach

Abstract

Two experiments were conducted to investigate manifestations of anxiety at the subjective and physiological level of analysis (Experiment 1), and behavioural level of analysis (Experiment 2). Anxiety was manipulated in novice climbers by using a climbing wall with routes defined at different heights (low and high). We measured self-reported state anxiety, heart rate (Experiments 1 and 2), blood lactate concentration and muscle fatigue (Experiment 1), and climbing time and fluency of movements (Experiment 2). In Experiment 1, climbing times were standardised. At the level of subjective experience we found that when participants climbed a route high on a climbing wall they reported significantly more anxiety than when they traversed an identical route low on the climbing wall. At the physiological level, they exhibited significantly higher heart rates, more muscle fatigue, and higher blood lactate concentrations. Experiment 2 showed that state anxiety also affected participants' movement behaviour, which was evidenced by an increased geometric index of entropy and by longer climbing times. It was concluded that anxiety indeed manifested itself at all three levels, and anxiety may induce a temporary regress to a form of movement execution that is associated with earlier stages of motor learning.

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Introduction

In the eyes of coaches, trainers, sport psychologists, and athletes it is important to control anxiety in sport situations in order to optimise performance. Too much anxiety, fear, or stress, may impair sport performance. Not surprisingly, many people within the world of sport are intrigued by competitive anxiety and how it can be controlled either by reducing it or by learning to cope with it when facing competition.

Although the relationship between anxiety and performance in sport has received considerable research attention (for overviews see for example Gill, 1994; Gould & Krane, 1992, Hackfort & Schwenkmezger, 1993; Jones, 1995b; Landers & Boutcher, 1998; Raglin, 1992; Raglin & Hanin, 2000; Smith, Smoll, & Wiechman, 1998, and Weinberg, 1989, 1990), "research findings have proved equivocal, with little evidence of the predicted relationships" (Jones, 1995a, p. 461). The frequent use of global performance measures (e.g., win or lose; hit or miss) is proposed as one of the possible reasons for the disappointing results to find support for the theoretical predictions. These outcome scores—denoting a product-oriented approach—may be too insensitive to detect significant anxiety effects (e.g., Parfitt, Jones, & Hardy, 1990; Weinberg, 1990). So far only few studies directly examined the *processes* by which performance mediation may take place (Collins, Jones, Fairweather, Doolan, & Priestley, 2001; Collins, Priestley, & Jones, 1996; Jones, Collins, & Doolan, 1998; Mullen & Hardy, 2000).

A process-oriented approach of the study of the relationship between anxiety and performance would not only consider changes in outcome but also changes in the execution of movements that might or might not lead to changes in outcome (Gould & Krane, 1992; Weinberg, 1989). In the present study we take such a process-oriented approach and investigate movement behaviour of participants placed in a threatening situation. We follow the general idea that an emotion, and hence anxiety, may manifest itself at three levels, namely, the level of subjective experience, the physiological level, and the behavioural level (e.g., Eysenck, 1975; Frijda, 1986; Hackfort & Schwenkmezger, 1993; Hanin, 2000; Lazarus, 2000; Vallerand & Blanchard, 2000).[1] For a full understanding of the effects of anxiety on performance it is important to gain insight at these three levels. However, there has been hardly any research taking all three levels into account. Especially the (movement) behavioural aspects remain under-exposed (see also, Hanin, 2000). In the current study we

[1] Other categorisations are possible, for instance, the well-known division of anxiety in cognitive and somatic anxiety and self-confidence (Martens, Vealey, & Burton, 1990), or Hanin's (2000) classification into seven components (cognitive, affective, motivational, bodily-somatic, motor-behavioural, performance, and communicative). We consider the division in the subjective, physiological and behavioural level most appropriate for the purposes of the current study. The distinction between cognitive anxiety, somatic anxiety, and self-confidence does not capture the behavioural level, and most of Hanin's rather detailed seven components are captured by the three more general levels used in this study.

examined the manifestations of anxiety at the three levels. In Experiment 1 we focussed on the subjective experience of anxiety and on concomitant physiological changes, both in autonomic variable heart rate and in muscle fatigue. In Experiment 2 we took a first step in investigating whether and how these covert manifestations of anxiety are accompanied by changes in participants' overt movement behaviour.

In the literature there has been little attention for the consequences of state anxiety on movement execution, pre-eminently the level of interest for athletes, coaches, physical educators, sport psychologists, and others. Notable exceptions in this regard are the studies by Weinberg (1978; Weinberg & Hunt, 1976), Allmer (1983), Beuter and Duda (1985; Beuter, Duda, & Widule, 1989), and the more recent studies by Collins et al. (1996, 2001), Jones et al. (1998), and Mullen and Hardy (2000). These studies were aimed at investigating the processes that underlie performance affected by anxiety either by measuring the electromyographic (EMG) activity of the muscles (Weinberg, 1978; Weinberg & Hunt, 1976), by studying movement characteristics such as the angle between upper leg and upper body (Allmer, 1983), by examining kinematic characteristics of a particular movement (Beuter & Duda, 1985; Collins et al., 1996, 2001; Jones et al., 1998; Mullen & Hardy, 2000), or by making kinetic analyses of movements (Beuter et al., 1989).

The results of the studies just cited support the contention that changing an individual's state (i.e., making him or her more anxious) can alter the characteristics of movement. For instance, anxiety is accompanied by movements that are less smooth, less efficient in terms of time and energy, and less variable (e.g., Beuter & Duda, 1985; Weinberg & Hunt, 1976). As indicated by Gould and Krane (1992), specifying the changes occurring in the execution of movements under high-anxiety conditions may provide insight into the question when performance may be impaired under the influence of anxiety and when no effects on performance may be expected. Therefore, one of the aims of the present study was to address anxiety-related changes in movement behaviour.

Thus far, the anxiety and motor performance research has specifically centred around the paradoxical performance effect or 'choking under pressure', that is, "... the occurrence of inferior performance despite individual striving and situational demands for superior performance." (Baumeister, 1984, p. 610). Several attentional models have been put forward to explain debilitating effects of anxiety on performance such as the 'distraction' model (Wine, 1971) and the 'self-focus' model (Baumeister, 1984). Especially the self-focus model has recently received empirical support (e.g., Beilock & Carr, 2001; Lewis & Linder, 1997). It states that pressure raises self-consciousness about performing correctly, and that the increased attention to skill execution together with the subsequent step-by-step control is thought to disrupt the normal processing of the task (see also, Jones, 1990; Lewis & Linder, 1997; Mullen & Hardy, 2000). Masters (1992, 2000) explicated the role of explicit *and* implicit knowledge in the disruption of the automaticity of a skill under pressure. According to Masters (1992, 2000), increased state anxiety and explicit knowledge about task performance may induce conscious control that disrupts the normal, automatic processing of the task at hand. The studies of Hardy, Mullen, and Jones (1996) and Mullen and Hardy (2000) produced evidence supporting Masters' (1992) 'conscious processing hypothesis'.

In these studies the renewed conscious control under pressure is seen as a temporary regress to a lower skill level—that is, to an earlier stage of learning, an idea that links back to stages of perceptual-motor learning introduced by Fitts and Posner (1967). After the cognitive and associative phases of learning, movement execution in the final autonomous phase is nearly fully automated (Fitts & Posner, 1967). Cognitive control of movements is no longer necessary. In fact, it is widely accepted that such cognitive control may be detrimental to skilled performance as it interferes with the well-learned automatisms of the skill. Thus, in going through these stages of learning the cognitive involvement in perceptual-motor control slowly diminishes. Following these ideas, a temporary regress to an earlier stage of motor learning would have to incorporate a reinvestment of cognition in perceptual-motor control, similar to the arousal-induced conscious control in Master's (1992, 2000) conscious processing hypothesis.

To not only investigate a rather dramatic end product of the inability to cope with anxiety—choking—we follow Masters' (1992) suggestion to also examine the processes underlying anxiety-related performance decrements and to search for behavioural concomitants of anxiety. In this search we set out from the hypothesis that anxiety results in a movement execution that is also associated with movements found at a lower skill level.

What can we expect to find at the behavioural level? Early in the process of mastering a perceptual-motor skill, performance is slow, irregular, and requires much effort. A common experience when starting to learn a new skill is that parts of the body, or sometimes even the whole body, are held rigid (think of your first dancing lessons). Bernstein (1967) called this the freezing of excessive biomechanical degrees of freedom necessary to turn the motor apparatus into a controllable, yet inefficient, system. It results in errors and inconsistent performance (Magill, 1998) with jerky, clumsy, and erratic movements (den Brinker & van Hekken, 1982; Vincken & Denier van der Gon, 1985; Whiting, Bijlard, & den Brinker, 1987). Learning a task may be characterized by a gradual release of the rigid couplings between parts of the body, that is, by a release of the degrees of freedom. This 'freeing' of degrees of freedom turns the motor apparatus into a controllable and efficient system, which would result in smoother and more fluent movements (Vereijken, van Emmerik, Whiting, & Newell, 1992).

Recently, the evolution from irregular, jerky movements to regular, smooth movements has also been studied from the perspective of dynamical systems theory, a branch of mathematics concerned with the analysis and formal modelling of complex time series. A key notion in this theory is that of dimensionality, that is, the number of active dynamical (i.e., as opposed to biomechanical) degrees of freedom[2] that are required to portray or model a system's trajectory or succession of states. For instance, to identify the state and future trajectory of an ordinary second-order mass-spring system two active degrees of freedom are required: position and velocity; if these are known, the acceleration of the system follows uniquely from the laws of motion. For more complex trajectories, such as a movement trajectory, the number of active degrees of freedom is unknown a priori, but may be estimated using a variety of analytical tools. Mitra, Amazeen, and Turvey (1998) applied one of these techniques (Abarbanel's phase-space reconstruction method) to movement trajectories obtained during intermediate learning of a bimanual rhythmic coordination task. They found that intermediate learning gradually and monotonically reduces the number of active degrees of freedom of the learned coordination dynamics, implying a reduction in dimensionality.

There are parallels between the movement characteristics of early learning and those of performance under pressure. Just as in the beginning of the learning process, under the influence of anxiety performance is also characterized by rigid and jerky movements, and a stiffening of the body that resembles the freezing of biomechanical degrees of freedom as described by Bernstein (1967) in early learning, and that is probably accompanied by an increase in the number of active degrees of freedom in the sense of dynamical systems theory. Movement behaviour accompanying anxiety is tense resulting from "generalized muscular tension, wholly or partly independent of overt movement" (Frijda, 1986, p. 40). A rigid posture and jerky movements are discernible characteristics of this tenseness, just as early in learning.

In the present study we will focus on effects of anxiety using psychological, physiological (Experiment 1), and behavioural measures (Experiment 2). Because we expect performance under anxiety to be tense, in Experiment 1, apart from changes in heart rate, we also investigated whether there is a difference in muscle tension in anxious and non-anxious movement execution. To obtain an indication of muscle tension, we used muscle fatigue

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[2] Newell and Vaillancourt (2001) described the distinction between biomechanical degrees of freedom and active dynamical degrees of freedom as follows:

> In the tradition of mechanics and physics we use the term degrees of freedom as the number of independent coordinates required to uniquely describe the configuration of the system. Therefore, the term degrees of freedom is reserved for the potential configurations of the many physical components at each level of analysis of the system. In contrast, dimension is used to capture what has been called the number of active or dynamical degrees of freedom that are required to model the attractor dynamics of the movement system. There is often no obvious correspondence between the physical degrees of freedom of a system and the dimension of an attractor (…). (p. 696)

(blood lactate concentration and EMG) because a higher muscle tension would have to result in more muscle fatigue (Vincken & Denier van der Gon, 1985). In Experiment 2 we ask whether the expected muscle tension at the physiological level has repercussions for the smoothness of movement execution at the behavioural level as measured with the 'geometric index of entropy' (Cordier, Mendès France, Bolon, & Pailhous, 1993; Cordier, Mendès France, Pailhous, & Bolon, 1994), a variable we will explain in the introduction to Experiment 2 and that may be connected conceptually to the notion of active dynamical degrees of freedom introduced before. As a result of the higher muscle tension we expected jerkier, more rigid movements in anxiety provoking than in anxiety-neutral situations, and, therefore, a higher geometric index of entropy.

A crucial aspect of studying the effects of anxiety on movement behaviour is the way in which anxiety is manipulated. The common approach to manipulate anxiety is to use the 'cognitive ego stressor method': Via several steps of giving negative feedback on performance anxiety is provoked (e.g., Beuter & Duda, 1985; Beuter et al., 1989; Bootsma, Bakker, van Snippenberg, & Tdlohreg, 1992; Mullen & Hardy, 2000; Weinberg, 1978; Weinberg & Hunt, 1976; Weinberg & Ragan, 1978). There are, however, some disadvantages to this method. First, negative feedback may compel participants to change their movement behaviour in a way they did not prefer initially. The change in movement behaviour may lead to a decrease in performance and to the wrong conclusion that anxiety impaired performance (Bakker, 1981). Second, most studies using the ego-stressor method managed to provoke only mild forms of anxiety that are below those typically found during competition (Williams & Elliott, 1999). Third, the ego-stressor method can cause an inward focus of attention that may in itself result in disruption of the automatism of the skill (Masters, 1992, 2000).

In the present study, we manipulated anxiety in a natural way by using a climbing wall where different heights provided different anxiety conditions. Some authors would rather speak of fear in this case, because of the presence of real physical danger (Morris, 1997; Spielberger 1966). Apart from the presence or absence of physical danger fear and anxiety have similar characteristics. Therefore, in this study we considered fear and anxiety as synonyms, which fits with the broad definition of anxiety given by Schwenkmezger and Steffgen (1989):

> *Anxiety* can be regarded as a broad concept for a number of very complex emotional and motivational states and processes that occur as a result of threat. This threat is related to the subjective evaluation of a situation, and concerns jeopardy to one's self-esteem during performance or social situations, physical danger, or insecurity and uncertainty (pp. 78-79).

Thus, the climbing wall provides an ecologically valid environment for the execution of climbing movements, and hence, an attractive location for studying the relationships between anxiety and performance (Jones & Hardy, 1990). Participants were asked to perform a climbing task in a threatening condition, that is, high on the climbing wall, and in a non-threatening condition, low on the wall[3].

Although the climbing task was new to the participants when they entered the experiments, the climbing route was very easy and readily learned before actual testing started. In this regard, Fitts (1964) remarked that for simple skills the earliest learning phase may be of very short duration "covering only the time required to understand instructions, to complete a few preliminary trials, and to establish the proper cognitive set for the task" (p. 262). Therefore, and because performance decrements under pressure may occur irrespective of skill level and ability (Baumeister, 1984), we considered this task (the execution of which may not have been fully automated) suitable for testing our hypotheses.

Experiment 1

Method

Participants

Thirteen participants, 5 male and 8 female, aged 20 to 30 years, volunteered to participate in the experiment. The participants, mainly college students, had no experience in climbing, and were naive to the purposes of the experiment. They were paid a small fee for their participation.

As a standard check, the Dutch version of the A-Trait scale of the State-Trait Anxiety Inventory (STAI)[4] was used to measure trait anxiety (Spielberger, Gorsuch, & Lushene, 1970; van der Ploeg, Defares, & Spielberger, 1979). The mean trait anxiety score for the male participants was 36.4 (SD = 10.62), and for female participants 31.8 (SD = 4.94). The mean score of male participants was comparable with the mean score for Dutch male college students reported by van der Ploeg, Defares, and Spielberger (1980), [mean (M) = 36.1, t = 0.06, *ns*, t test between a sample and a population mean, Thomas & Nelson, 1996]. The female participants were significantly less trait anxious compared to Dutch female college students (M = 37.7, van der Ploeg et al., (1980), $t(7) = 3.38$, $p < .05$, t test between a sample

[3] Jones (1995b; Swain & Jones, 1996) claims that direction of anxiety—whether anxiety is perceived as debilitative or facilitative—should also be taken into account when studying the effects of anxiety. However, Jerome and Williams (2000) argue that the results concerning this issue are equivocal. In addition, in the current study the focus is on *changes* as a result of anxiety either for better or worse. Therefore, in this study we did not consider direction of anxiety.

[4] The STAI A-Trait scale is a self-report questionnaire that measures anxiety proneness, that is, the tendency to respond to situations perceived as thrilling with an elevation in state anxiety intensity. Scores range from a low of 20 to a high of 80 (van der Ploeg, Defares, & Spielberger, 1979).

and a population mean). The results indicate that the participants had no extraordinary tendency to respond to situations perceived as threatening with an elevation in state anxiety (e.g., Smith et al., 1998).

Experimental Set-up

Participants climbed on a 10^{o} inclined artificial wall (width: 3.5 m; height: 7.0 m; see Figure 2.1), which was placed in a large experimentation room. The wall consisted of 9 laminate panels with a grey grainy texture for friction. Holds of varying shape and size could be bolted almost anywhere on the wall.

On the wall, two identical, horizontal routes (so called 'traverses', built by a professional route designer) were mounted (see Figure 2.1). Each traverse consisted of five footholds and six handholds of varying size and shape, all suitable for novice climbers. The traverses could be easily mastered within minutes of practice. The mean height of the five footholds of the low traverse was 0.3 m (*low* condition); the mean height of the five footholds of the high traverse was 5.1 m (*high* condition). To be able to start with the high traverse in the same physical condition as in the low traverse, a movable platform, 5.0 m above the floor, was placed 1.2 m in front of the climbing wall.

All participants wore well fitting climbing shoes (Enduro 954, La Sportiva). In the high condition, participants wore an integral harness (Edelrid), connected to a climbing rope. A standard protection technique was used to ensure the safety of the participants. One of the experimenters served as belayer. The use of chalk was permitted.

To determine the manifestations of anxiety at the level of subjective experience we used the 'anxiety thermometer' validated by Houtman and Bakker (1989). The anxiety thermometer is a 10-cm continuous scale on which participants were asked to rate their anxiety feelings at a particular moment, ranging from 0 (*not anxious at all*, the left end) to 10 (*extremely anxious*, the right end). Individuals had to place a cross on the 10 cm scale to indicate how they felt at a particular moment. The distance between the left end and cross (in cm) was used as a measure of the reported anxiety. Consequently, it is a quick way to measure state anxiety, in contrast to the often-used Competitive State Anxiety Inventory-2 (CSAI-2, Martens, Vealey, & Burton, 1990), which would be unsuitable for our purposes. In this regard it should be noted that the anxiety thermometer does not take into account the distinction between cognitive and somatic anxiety as measured with the CSAI-2. Anxiety thermometer scores appear to correlate equally with cognitive anxiety scores and somatic anxiety scores on the CSAI-2, on average $r = .59$ and $r = .62$, respectively (Bakker, Vanden Auweele, & Van Mele, 1996). For each measurement, a separate anxiety thermometer was used.

During climbing we recorded heart rate values every 5 seconds using a Sporttester (Polar Electro-3000). Afterwards, for every climb the mean heart rate was calculated. The blood lactate concentration of capillary blood samples (10 μl) was determined using photospectrometry (Dr. Lange, Mini 8).

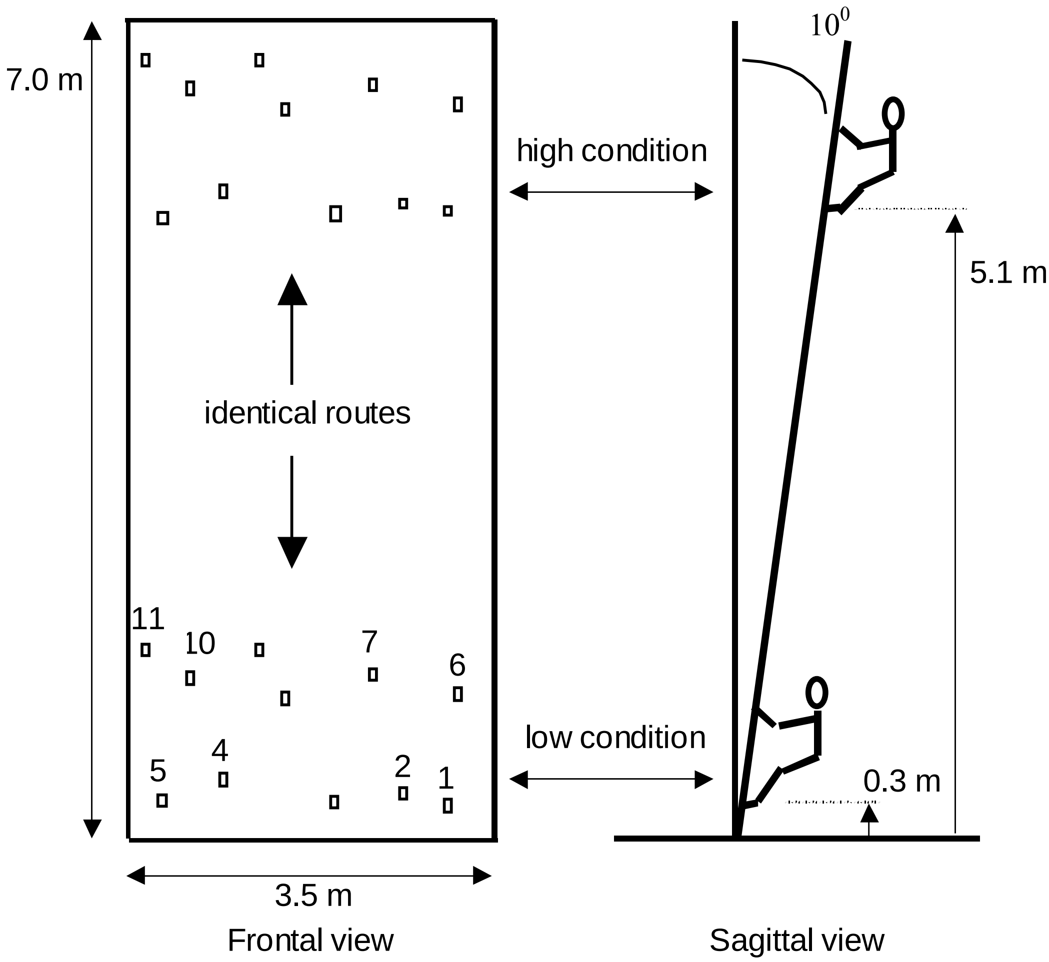

Figure 2.1. *Front view and side-view of the climbing wall used in Experiments 1 and 2. In Experiment 2 the climbing wall was placed perpendicular.*

To measure muscular fatigue we followed the guidelines of Petrofsky, Glaser, Phillips, Lind, and Williams (1982) using the decrease of the median frequency of the power spectrum of the EMG-signal of the 'hand-grip muscles' (see also Gamet & Maton, 1989). Participants performed an isometric contraction on a handgrip dynamometer (Lafayette Instrument Co., ranging from 0 to 100 kg with the distance between the palm of the hand and the phalanxes being adjustable to hand size). During this contraction the electrical activity of the flexor muscles in the forearm was measured (surface EMG). The placement of the two bipolar silver-silver-chloride surface electrodes (Medi-trace, ECE 1801) was on the diagonal line from the medial epicondyle of the humerus to the styloid of the ulna, at one third proximal. The interstice of the electrodes measured 2.5 cm. A reference electrode was placed on the lateral condyle of the humerus. The EMG was measured by a differential amplifier (DISA, type 15C01, Skovlunde, Denmark) using a bandwidth of 10-200 Hz. The signal was sampled by a 12 bits A/D-convertor at 1000 Hz, and stored in a computer. The median frequency of the power spectrum of the EMG-signal was calculated by using a Fast Fourier Transformation.

The size of the grip of the dynamometer was adjusted for each participant (second joint of the middle finger of the hand holding the dynamometer was bent at a 90^o angle). The participants sat at a table with their arm resting on the table; the arm was bent at about 90^o angle and supinated. Maximal grip strength was determined beforehand (see *Procedure*) by having the participants squeeze the dynamometer with their preferred hand with maximal force. This was done three times. The best score was taken as the final result. During the experiment participants were asked to squeeze the dynamometer with 50% of their maximal force for at least 3 s. This was done twice in each condition, namely, before and after climbing. We took 50% of the maximal voluntary contraction (MVC) to ensure that for all squeezes the same force was generated. This guaranteed honest comparisons of muscle activity between the low and high conditions. During the isometric contractions the EMG activity was recorded. The median frequency before climbing and the median frequency after climbing were calculated and the difference in both median frequencies was used as index of muscle fatigue. Petrofsky et al.'s (1982) investigation showed that this is "... a good non-invasive index of muscle fatigue" (p. 221). As mentioned in the *Introduction*, together with blood lactate concentration we used this index of muscle fatigue as indirect measure of muscle tension.

Procedure

For each participant (tested individually) the experiment was spread over three days. *Day 1* was intended to familiarize participants with the procedure of the experiment and to learn the task they had to perform. Participants were first informed in general terms about the aims and procedure of the experiment. Next they signed a statement of informed consent and completed the Dutch version of the STAI A-Trait scale (van der Ploeg et al., 1979). Then the maximal voluntary grip strength was determined (left or right hand by choice). Three minutes later participants practised the traverse five times back and forth in the low condition ensuring that they could easily execute the task (at least in the low condition).

On *Day 2* (three to ten days after Day 1) participants received a more detailed explanation of the procedure. Subsequently, the electrodes to measure EMG activity and the Sporttester were placed, and participants put on their climbing shoes and harness.

Seven minutes before climbing participants performed an isometric contraction with their preference hand on a handgrip dynamometer, during which the EMG activity was recorded. Six minutes before climbing participants took a seat either on the floor or on the platform. One minute before climbing participants filled out the anxiety thermometer (Houtman &

Bakker, 1989). Then, starting at the right side of the wall participants climbed the traverse 6.5 times in the high or in the low condition (counterbalanced) with a set traverse time of 20 seconds. Hence, the total climbing time was 2 minutes 10 seconds. In the high condition the belayer lowered the participant using a standard technique to safely bring back participants to the floor. After climbing, participants immediately took a seat. They were asked to recall how anxious they had felt during climbing and to record this on the anxiety thermometer scale. The mean of the two anxiety scores in each condition was used as an anxiety score for that condition. After 1.5 minutes participants again performed an isometric contraction on the handgrip dynamometer during which the EMG was recorded. Three minutes after climbing a blood sample was obtained from the participants' thumb and the blood lactate concentration was measured.

On *Day 3* (three to ten days after Day 2) the procedure of Day 2 was repeated. The order of the conditions, however, was reversed.

Statistical analysis

The effects of Height (low condition, high condition) and Day (Day 2, Day 3) were tested with four two-factor within-subject analyses of variance (ANOVAs) with repeated measures on either anxiety thermometer scores, muscle activity indices, blood lactate concentrations, or heart rates. Eta squared (η^2) assessed the explained variance in the ANOVA models. Pair-wise comparisons were made to identify specific mean differences when appropriate. In these cases the Bonferroni method (Kinnear & Gray, 2000) was used requiring the alpha level to be adjusted to .008.

Results

The mean maximal voluntary grip strength of the participants was 43.4 kg (SD = 11.67), which is a normal grip strength for non-climbers (cf. Grant, Hasler, Davies, Aitchison, Wilson, & Whittaker, 2001; Grant, Hynes, Whittaker, & Aitchison, 1996).

Subjective experience of state anxiety

The ANOVA performed on the anxiety thermometer data revealed that participants reported significantly more anxiety in the high condition (M = 4.3, SD = 2.39) than in the low condition (M = 1.5, SD = 1.28), $F(1, 12) = 28.03$, $p < .001$, $\eta^2 = .70$. Scores did not differ significantly between Day 2 and Day 3. Also the interaction was not significant.

State anxiety at a physiological level

Heart rate

The mean heart rate was significantly higher in the high condition (M = 164.8, beats per minute, bpm, SD = 14.06) than in the low condition (M = 146.1 bpm, SD = 18.07), $F(1, 12)$ = 101.69, $p < .001$, $\eta^2 = .89$. There was also a significant interaction between Height and Day, $F(1, 12) = 6.26$, $p < .05$, $\eta^2 = .34$. In the low condition on Day 2 (M = 143.9 bpm, SD = 17.76), the mean heart rate was significantly lower than in the low condition on Day 3 (M = 148.4 bpm, SD = 19.17), $t(12) = 2.08$, $p < .006$). In the high condition the mean heart rate on Day 2 was 165.8 bpm (SD = 13.06) and on Day 3 163.8 (SD = 15.36). This difference was not significant ($p > .008$). The significant difference between Day 2 and Day 3 in the low condition was probably due to day-to-day heart rate fluctuations (see Table 2.1). Of particular relevance here is that the mean heart rate in the high condition was significantly higher than in the low condition.

Table 2.1. *Heart rate*[a] *(mean and standard deviation) for the conditions in Day 2 and Day 3 (Experiment 1).*

	Day 2 Condition		*Day 3 Condition*	
	Low anxiety	*High anxiety*	*Low anxiety*	*High anxiety*
Starting in low-anxiety condition	133.9 (15.45) (n = 7)	158.3 (11.80) (n = 7)	160.9 (12.19) (n = 6)	174.5 (11.62) (n = 6)
Starting in high-anxiety condition	155.5 (13.00) (n = 6)	174.6 (8.50) (n = 6)	137.6 (17.87) (n = 7)	154.7 (12.15) (n = 7)
Mean	143.9	165.8	148.4	163.8
SD	17.76	13.06	19.17	15.36

[a]In bpm.

Muscle tension

Visual inspection during the experiment made clear that participants were able to accurately squeeze the handgrip dynamometer at 50% of their MVC with minimal variations only. No further records of the squeeze accuracies were made.

The index of muscle fatigue and the blood lactate concentration were influenced by the height of climbing. The index of muscle fatigue was significantly higher in the high condition (M = 8.2, SD = 5.76) than in the low condition (M = 4.8, SD = 6.74), $F(1, 12) = 6.64$, $p < .05$, $\eta^2 = .36$, as was the blood lactate concentration (high condition: M = 7.2 mmol/l, SD = 1.91; low condition: M = 6.0 mmol/l, SD = 1.26), $F(1, 12) = 6.42$, $p < .05$, $\eta^2 = .35$. No other significant effects were found.

Discussion

The purpose of Experiment 1 was to investigate manifestations of anxiety at the level of subjective experience and at the physiological level by means of heart rate, muscular activity, and blood lactate concentration. Self-report scores indicated that participants felt more anxious in the high condition than in the low condition. By comparison, the height of the scores suggests that participants felt more anxious than students who are about to enter a written examination (Houtman & Bakker, 1989); they felt about as anxious as novice teachers just before a lecture (Houtman, 1990); and they were less anxious than youth speed skaters prior to the start of a 1500 m race at a national championship (Bakker, Vanden Auweele, & Moormann, 1992). In addition to the subjective experience, heart rate appeared to be higher high on the wall than low on the wall. We found that these manifestations of anxiety went hand in hand with more muscle fatigue and a higher blood lactate concentration indicating more muscle tension as would also be expected when there is a renewed freezing of degrees of freedom.

An issue to pursue is whether these subjective and physiological changes associated with anxiety have repercussions at a (movement) behavioural level, the remaining level at which anxiety may manifest itself (e.g., Frijda, 1986). We addressed this issue in Experiment 2.

Experiment 2

A possible explanation for performance decrements coinciding with anxiety may be a regress to earlier stages of motor learning (e.g., Baumeister, 1984; Fitts & Posner, 1967; Hardy, 1999; Masters, 1992, 2000; Mullen & Hardy, 2000) characterized by higher muscle tension, and rigid and jerky movements. In Experiment 1 we showed that anxiety is accompanied by more muscle fatigue indicating a higher muscle tension. In Experiment 2 we examined whether anxiety is also accompanied by rigid and jerky movements as would be expected if a regress to lower skill levels occurs. In order to do so we measured the fluency of participants' climbing movements by using a 'geometric index of entropy' (Cordier et al., 1993, 1994). Just as the complexity of a spatial-temporal trajectory may be assessed by means of its dimensionality, the geometric index of entropy (in short, 'entropy') can be used to assess the complexity of a spatial trajectory, or path (Cordier et al., 1993, 1994). In sport climbing the entropy can be defined as the fluency of the curvature that arises from the displacement of the body centre of gravity when climbing a route (Cordier et al., 1993, 1994; see Figure 2.2). Mathematically entropy (H) is described by the following equation (see Cordier et al., 1993, 1994):

$$H = \log_n(2L/c)$$

where L is the length of a curve, and c the convex hull of that curve (see Figure 2.2).

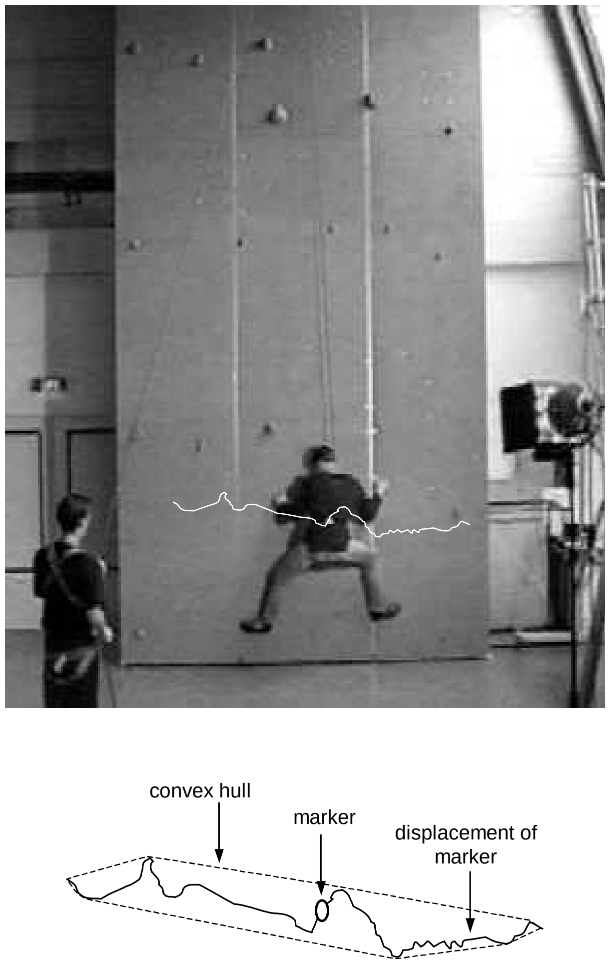

Figure 2.2. *Front view of the climbing wall with the marker curve. The low and high traverses were identical. The principle of assessing the index of geometric entropy is shown below the picture of the wall (cf. Cordier et al., 1993, 1994). (See text for more details.)*

Cornier et al. (1993, 1994) argued that there is a clear-cut correlation between the smoothness of a climber's trajectory and the climber's expertise. The more skilled a climber is, the more fluent the shape of his or her trajectory, and the lower the entropy of the trajectory. The authors indeed showed that entropy decreases as learning progresses, which is consistent with the decrease in dimensionality of spatiotemporal trajectories observed by Mitra et al. (1998) for intermediate learning. In Experiment 2 we use entropy and its mathematical components to empirically investigate the idea that performance decrements associated with anxiety can be explained by a temporary regress to a movement execution associated with earlier stages of motor learning. If such a regress occurs, less fluent movements are expected, and hence, entropy should increase. Both a larger L and a smaller c will contribute to a higher entropy. Because we expected more rigid, jerky movements when anxious, we hypothesised that L would be larger, for the movement trajectory would be noisier. Due to a stiffening of the body, with movements of the centre of gravity taking place in a smaller motor work space, we also expected *c* to be smaller in the threatening condition than in the non-threatening condition. An increase in entropy as a result of anxiety would be consistent with the idea of a regress to earlier learning (Cordier et al., 1993, 1994).

Method

Participants

Seventeen college students, 11 male and 6 female, aged 19 to 26 years, volunteered to participate in the experiment. None of them participated in Experiment 1 and none had experience in climbing. All participants were naive to the purposes of the experiment.

The mean trait anxiety score for the male participants was 30.3 (SD = 2.49) and for the female participants 33.2 (SD = 4.79). The mean score of male participants was significantly different from the mean score for Dutch male college students (M = 36.1) obtained by van der Ploeg et al. (1980) [$t(10) = 7.73$, $p < .05$, *t* test between a sample and a population mean, Thomas & Nelson, 1996]. The mean score of the female participants was comparable with the mean score for Dutch female college students reported by van der Ploeg et al. (1980) (M = 37.7), ($t = 2.30$, *ns*, *t* test between a sample and a population mean, Thomas & Nelson, 1996). The results indicate that the participants had no extraordinary tendency to respond to situations perceived as threatening with an elevation in state anxiety (e.g., Smith et al., 1998).

Experimental Set-up

Participants again climbed on the climbing wall in a high and low condition. This time the wall was not inclined but vertical and no time constraints were imposed. Again two identical, horizontal routes (traverses) were mounted on the wall each consisting of six handholds and five footholds (see Figure 2.2). As in Experiment 1, the mean height of the footholds of the low traverse was 0.3 m (*low* condition). The mean height of the footholds of the high traverse was not as high as in Experiment 1 because at this height (5.1 m) it was not possible to make the required video recordings to determine entropy. Therefore, the mean height of the footholds of the high traverse was 3.7 m (*high* condition). To enable participants to start climbing in the high condition a large stepladder was used. The stepladder had a small platform that allowed the participants to rest after having climbed it and to start the high traverse in the same physical condition as in the low traverse.

As in Experiment 1 participants wore well fitting climbing shoes and an integral harness connected to a climbing rope. The same security procedure as in Experiment 1 was used, but now this was done in both the high and the low condition to ensure similarity of the conditions (apart from the height, of course). This is especially relevant in this experiment because the presence of the security rope might, in principle, have an effect on the entropy, the most relevant dependent variable. All climbs were recorded using an S-VHS camcorder (sampling rate of 50 Hz) placed 12 m in front of and perpendicular to the climbing wall at a height of 2 m.

Procedure

Participants were tested individually and on a single day. The experiment lasted approximately two hours. The entire procedure was explained to each participant. Participants were then asked to read and sign a statement of informed consent and to fill out the Dutch version of the STAI A-Trait scale (van der Ploeg et al., 1979).

After participants had put on their climbing shoes and harness, and placed the Sporttester, they practised climbing on the wall (low traverse). Climbing advice was given to participants when needed. Practice periods lasted from 5 to 10 minutes and stopped when participants were able to successfully complete the traverses on the wall. In this way it was ensured that participants had mastered the task and that an eventual failure of a participant to complete the task in either condition would not be due to lack of experience with the task. After practising participants were allowed 20 minutes to fully recuperate.

Five minutes before each condition, the participant was positioned in front of the wall, either on the floor or the stepladder. Two minutes before the climb participants were asked to indicate how anxious they were at that moment by filling out the anxiety thermometer (Houtman & Bakker, 1989). Then, the participant was connected to the rope. Use of chalk was permitted. The participant was instructed to begin when ready by taking the starting position on the wall. Participants were in the starting position when they had placed their right hand on Hold 6 (see Figure 2.1), their left hand on Hold 7, their right foot on Hold 1, and their left foot Hold 2. In the high condition, as soon as the participant had taken this position, the stepladder was removed to make sure that in the event of a fall he or she would not hit it.

The participants resumed the same position after they had climbed the traverse two times. Hence, participants climbed the traverse from the right to the left (ending with right hand on Hold 10, left hand on Hold 11, right foot on Hold 4, and left foot on Hold 5; see Figure 2.1), and back to the right again. Immediately after the climb, the participants were asked to recall how anxious they had felt during climbing and to record this on the anxiety thermometer. The mean of the two anxiety scores (before and after the climb) was used as an anxiety score for that climb (and thus, for that condition).

After a recuperation time of about one hour the procedure was repeated, but now participants climbed in the other condition (high if they had started low; low if they had started high). The order of high and low conditions was reversed with every new participant.

Dependent variables

Trait and state anxiety and heart rate were measured in the same way as in Experiment 1. As explained in the introduction to Experiment 2 we used the geometric index of entropy

(Cordier et al., 1993, 1994) to measure participants' fluency of movements. To calculate the entropy, a marker was mounted at the participant's back (see Figure 2.2). The marker was attached to a belt that was secured around the participant's waist. Afterwards, the position of the marker was determined from video (using WINanalyze software package, version 1.4 3D by Mikromak GmbH) so that the length of the marker line, the convex hull, and the entropy could be calculated.

Because climbing time was not standardised as in Experiment 1 we also determined climbing time from video to determine whether anxiety had an effect on the speed of climbing. It was defined as the sum of the time needed to climb the two traverses (from the right to the left, and back) in each of the two conditions. Time started as soon as participants released one of the holds in the starting position, thus, as soon as the first movement was initiated. When the participant had returned to the starting position after climbing the two traverses, the time was stopped.

Statistical analysis

The effects of Height (low condition, high condition) were tested using one-tailed paired *t* tests. Effect sizes of within factor (ES_w) were calculated to provide an estimation of the meaningfulness of a difference between two means (Mullineaux, Bartlett, & Bennett, 2001; Thomas & Nelson, 1996). An effect size of 0.2 or less, about 0.5, and 0.8 or more, represents small, moderate, and large differences, respectively (Cohen, 1988).

Results and Discussion

Anxiety thermometer scores and heart rate

Participants reported significantly more anxiety in the high condition (M = 4.6, SD = 1.72) than in the low condition (M = 2.1, SD = 1.13), $t(16) = 10.10$, $p < .001$, $ES_w = 2.19$. The mean heart rate also differed significantly between conditions, $t(15) = 6.29$, $p < .001$, $ES_w = 0.99$, being higher in the high condition (M = 130.4 bpm, SD = 18.75) than in the low condition (M = 112.4 bpm, SD = 18.24). Thus, despite a somewhat lower height of the traverse in the high condition compared to that of the high condition in Experiment 1, the results indicate that the anxiety manipulation was again successful.

Entropy

Table 2.2 displays the entropy, the length of the climbing trajectory (L), as well as the convex hull (c) per condition. The mean entropy was significantly higher in the high (M = 1.112) than in the low condition (M = 1.013), $t(16) = 2.80$, $p < .01$, $ES_w = 0.95$, indicating a less fluent displacement of the centre of gravity under the influence of anxiety. Table 2.2 shows that 11 of 17 participants demonstrated a lengthening of the climbing trajectory in the high condition suggesting that the course of the body's centre of gravity seems to be somewhat more erratic when climbing in the high condition though the difference in *L* between high and low conditions was only marginally significant, $t(16) = 1.40$, $p = .09$, $ES_w = 0.48$. Moreover, the convex hull in the high condition appeared to be significantly smaller than in the low condition, $t(16) = 5.60$, $p < .001$, $ES_w = 0.97$, further explaining the higher entropy. The smaller convex hull indicates that the climbing trajectory was flattened in the high condition compared to the low condition, while the climbing routes were identical. Thus, displacements of the centre of gravity covered a smaller motor work space high on the wall.

Table 2.2. *Geometric index of entropy (H)[a], length of the climbing trajectory (L)[a], and convex hull of the climbing trajectory (c)[a] for the conditions in Experiment 2.*

Participant	*Condition*					
	Low anxiety			*High anxiety*		
	H	*L*	*c*	*H*	*L*	*c*
1	0.97	5.9	4.5	0.99	6.4	4.7
2	0.96	6.2	4.8	1.11	6.9	4.5
3	1.15	7.3	4.7	1.16	7.2	4.5
4	1.09	7.5	5.0	1.09	7.2	4.9
5	0.95	6.4	5.0	1.09	7.2	4.8
6	0.97	6.2	4.7	1.13	6.7	4.3
7	0.94	6.7	5.2	1.07	7.0	4.8
8	0.94	5.8	4.5	1.46	9.2	4.3
9	0.87	5.8	4.9	0.87	5.6	4.7
10	1.10	6.7	4.4	1.13	6.8	4.4
11	1.30	9.0	4.9	1.15	7.0	4.4
12	1.05	7.1	5.0	1.27	8.4	4.7
13	1.03	7.1	5.1	1.04	6.8	4.8
14	0.96	6.7	5.2	1.03	6.9	4.9
15	0.91	6.4	5.2	1.14	7.4	4.8
16	0.98	6.4	4.8	1.13	7.0	4.5
17	1.07	7.0	4.9	1.05	7.0	4.8
Mean	1.01	6.7	4.9	1.11	7.1	4.6
SD	0.104	0.77	0.23	0.124	0.77	0.20

[a]In m.

Climbing time

Table 2.3 shows the climbing time per condition. It appeared that the average climbing time increased significantly and by almost 50% from 29.5 s in the low condition to 43.1 s in the high condition, $t(16) = 5.59$, $p < .001$, $ES_w = 2.02$. Possible reasons why these climbing times were so much longer will be briefly discussed in the *General Discussion*. Note that the longer climbing time may partly explain the higher heart rates.

Together, the results clearly indicate that participants' climbing behaviour in the high condition differed from that in the low condition.

Table 2.3. *Climbing time[a] for the conditions in Experiment 2.*

Participant	*Condition*	
	Low anxiety	*High anxiety*
1	24.8	29.1
2	26.9	36.4
3	42.6	43.3
4	32.5	37.0
5	35.4	59.6
6	43.8	58.1
7	24.4	38.4
8	27.8	68.1
9	19.2	23.3
10	32.3	58.7
11	30.1	46.7
12	28.4	46.7
13	19.8	35.0
14	25.3	36.2
15	28.8	44.4
16	33.1	40.6
17	26.9	31.3
Mean	29.5	43.1
SD	6.72	12.11

[a]In s.

General Discussion

The main aim of this study was to examine the relationship between anxiety and motor performance. More specifically, we investigated the processes underlying the often-noticed impairment of performance associated with anxiety. To examine anxiety-performance relationships we investigated possible manifestations of anxiety at three levels, the level of subjective experience, the physiological level, and the behavioural level. Based on the literature on anxiety (e.g., Hardy, 1999; Masters, 1992; Mullen & Hardy, 2000), we argued that anxiety might disrupt movements leading to a type of movement behaviour characteristic of earlier stages of learning that would be characterized by stiffening of the body, and more rigid and jerky movements.

To manipulate anxiety we used height on a climbing wall. This manipulation offered a way to test participants in a natural, ecologically valid situation that is both safe and frightening (Baddeley, 1972; Idzikowski & Baddeley, 1987). In Experiment 1 we showed that with this manipulation, anxiety manifested itself both at the level of subjective experience as indicated by the higher anxiety scores, and at the physiological level as indicated by the higher heart rates, higher blood lactate concentrations, and more muscle activity. Because climbing times were standardised these changes could not be the result of, for instance, faster climbing (earlier fatigue) or slower climbing (e.g., with longer grasping of the holds and more fatigue). Thus, participants seemed to perform the climbing task in the threatening condition with more muscle tension than in the non-threatening condition.

In Experiment 2 we addressed the question whether the physiological changes found in Experiment 1 were also manifest in participants' overt movement behaviour. To examine this question we determined the fluency of the climbing movements by measuring the entropy. We found a higher entropy of climbing trajectory when participants climbed high on the climbing wall indicating a less smooth displacement of the body's centre of gravity that is also characteristic of less skilled climbing behaviour (Cordier et al., 1993, 1994). The higher entropy appeared to be the result of a somewhat longer climbing trajectory of the body's centre of gravity (L, see Figure 2.2) and, especially, a smaller convex hull (c, see Figure 2.2). Together these results show a noisier movement pattern and the use of smaller motor workspace to climb an identical route.

In addition, when no time constraints were imposed (Experiment 2), climbing time appeared to be no less than 46% longer in the high condition than in the low condition. Thus, apart from spatial changes, the temporal patterning of climbing movements changed as well. Other than noticing that a longer climbing time fits well with a more rigid, jerkier and less efficient movement pattern, it is difficult, with the variables measured in this study, to explain why this change in climbing time occurred. With entropy we investigated the movements of the centre of gravity but our results remained mute about the movements made with the limbs. Did participants make more limb movements, for instance? Did they grasp the holds longer? Or did they move slower from hold to hold? To gain further insight into the anxiety-performance relationship we investigated these questions in a follow-up study (Pijpers, Oudejans, & Bakker, 2005; see also Chapter 3 of this thesis). The preliminary results indicated that there were more explorative hand and foot movements—in part, this might explain the increase in entropy—, and that movements from one hold to another were actually slower in the high-anxiety condition than in the low-anxiety condition. These findings may partly explain the longer climbing times under anxiety provoking conditions. Additional research is required into the relation between entropy changes as found here and the changes in limb movements as found in our follow-up study.

All in all, the results support our hypotheses so that we can conclude that anxiety manifests itself at the level of subjective experience, at the physiological level as well as at the behavioural level. Furthermore, because anxiety resulted in an increase in muscle tension, longer climbing times, and an increase in entropy, we can also conclude that the physiological and movement behavioural changes displayed under anxiety conditions reflect a regress to a movement execution also characteristic of earlier stages of skill acquisition.

Our results are in line with those of Weinberg (1978; Weinberg & Hunt, 1976), and Beuter and Duda (1985; Beuter et al., 1989) who also found spatio-temporal changes in movement patterns under the influence of anxiety. In addition, the results are in accordance with the self-focus model of choking (Baumeister, 1984) or the conscious processing hypothesis (Masters, 1992; Mullen & Hardy, 2000) in which anxiety is assumed to evoke an inward focus of attention on the step-by-step execution of the movement. Consequently, movement control involves more cognitive processes.[5] As a result, just as when learning a new skill, parts of the body, or sometimes even the whole body, are held rigid. Or, in Bernstein's (1967) terms, one could say that excessive biomechanical degrees of freedom are frozen. From a dynamical systems perspective one could argue that more active dynamical degrees of freedom are required to describe the resulting spatial trajectory. Most important for now, it seems that performing a learned task in a threatening situation can be considered as performing a 'new', unfamiliar task for which a new solution has to be found.

This idea provides a simple explanation as to why repeated exposure to anxiety provoking situations results in a decrease in the effects of anxiety on performance (e.g., Frijda, 1986). Apart from habituation (less anxiety) one learns to execute the task under the influence of anxiety. In the beginning anxiety provides a new condition for which a new perceptual-motor solution has to be found. After repeated exposure one not just learns to execute the task, but one learns to execute the task under those specific conditions, that is, under the influence of anxiety. This would explain the well-known phenomenon that even experienced artists before coming on stage and experienced athletes before an important match or race are still very anxious, even though this normally does not impair their performance. They have learned to perform well under conditions of anxiety. Performing under pressure is no longer new and unfamiliar.

As a final point, the role of perceptual processes, not investigated so far, should be taken into consideration in the anxiety-performance research as well. Williams and Elliott (1999) noted that "successful performance in sport requires skill in perception, as well as the efficient and accurate execution of movement patterns" (p. 362). These authors found with respect to karate that high levels of anxiety increased the rate of visual scanning and the number of fixations on opponents' arms and fists, and as such their research is exemplary for the role of perception in anxiety-performance relationships. Hardy and Hagtvet (1996) alluded to this possible role of perception in the anxiety research by asserting that realistic attempts to model the anxiety-performance relationship need to consider the changes in perceptual processes that may accompany anxiety and underlie performance effects. However, only a few studies have assessed the effects of anxiety on perceptual processes in general, and almost no previous research has examined the effects of anxiety on perceptual processes in sport (Williams & Elliott, 1999).

In conclusion, research into anxiety-performance relationships may profit from the use of

[5] As an aside, these processes might perhaps also contribute to the longer climbing times, as performance involving these processes will take more time than a more automated execution of the task.

process measures. The use of outcome measures may provide indirect support for the idea that performance is affected by anxiety, but it does not allow conclusions as to why and how anxiety affected the actual movement execution (e.g., Bennett, 2000). Insight into these latter issues may have consequences for designing anxiety-reducing techniques. Thus, to answer the question why anxiety may impair sport performance it does not suffice to just explore the effects of anxiety on one's global performance. Instead, the intermediate steps between heightened anxiety and the eventual performance should also be investigated. In this respect, much work remains to be done in order to obtain a thorough insight into anxiety-performance relationships in sport.

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Chapter 3

Anxiety-induced changes in movement behaviour during the execution of a complex whole-body task

Abstract

We investigated the impact of anxiety on movement behaviour during the execution of a complex perceptual-motor task. Masters' (1992) conscious processing hypothesis suggests that under pressure an inward focus of attention occurs, resulting in more conscious control of the movement execution of well-learned skills. The conscious processes interfere with automatic task execution hereby inducing performance decrements. Recent empirical support for the hypothesis has focused on the effects of pressure on end performance. It has not been tested so far whether the changes in performance are also accompanied by changes in movement execution that would be expected following Masters' hypothesis. In the current study we tested the effects of anxiety on climbing movements on a climbing wall. Two identical traverses at different heights on a climbing wall provided different anxiety conditions. In line with the conscious processing hypothesis we found that anxiety had a significant effect on participants' movement behaviour evidenced by increases in climbing time and the number of explorative movements (Experiments 1 and 2) and by longer grasping of the holds and slower movements (Experiment 2). These results provide additional support for the conscious processing hypothesis and insight into the relation between anxiety, performance, and movement behaviour.

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Introduction

When the pressure is high, performance becomes less predictable. In sports, for example, some top athletes thrive under the pressure while others miserably fail, especially at these crucial moments of, for instance, a decisive penalty shot in soccer or a match point in tennis. What does it mean to execute perceptual-motor skills under high pressure? Why do some seem to benefit from stressful situations while others seem to suffer under those circumstances? In what way are movements different when they are executed in anxiety-provoking situations compared to more neutral situations? To answer the question why anxiety may influence expert performance it does not suffice to just explore the effects of anxiety on one's global performance (the 'end result of a motor act', Weinberg & Hunt, 1976). Instead, also the mechanisms affecting the performance should be considered such as changes in the execution of movements (e.g., Beuter & Duda, 1985; Collins, Jones, Fairweather, Doolan, & Priestley, 2001; Janelle, 2002; Martens, 1971; Mullen & Hardy, 2000; Schmidt, 1982; van Loon, Masters, Ring, & McIntyre, 2001; Weinberg, 1978). The (pioneering) work of Weinberg (1978; Weinberg & Hunt, 1976) and Beuter and Duda (1985; Beuter, Duda, & Widule, 1989) illustrated the importance of examining anxiety and accompanying changes in movement pattern. These authors demonstrated differences in co-ordination patterns suggesting less efficient movements in high-anxiety conditions. Obviously, insight into the relation between anxiety and movement behaviour may have implications for designing techniques to control anxiety in order to optimise performance on perceptual-motor skills in several domains such as sports (e.g., Gould, & Udry, 1994), dance (e.g., Wilson, 2002), making music (e.g., Stanton, 1994), police work (e.g., Anderson, Litzenberger, & Plecas, 2002; Le Scanff & Taugis, 2002), work of fire fighters (e.g., Ryan, Ployhart, Greguras, & Schmit, 1998), and armed forces (e.g., Arthur, Young, Jordan, & Shebilske, 1996).

Before we turn to the relation between anxiety and movement behaviour, we will define 'arousal', 'anxiety', and 'stress', terms that are surrounded by considerable confusion in the literature (e.g., Janelle, 2002; Landers & Arent, 2001; Landers & Boutcher, 1998; Woodman & Hardy, 2001). Landers and Arent (2001) recommend not using these terms interchangeably and to conceptually distinguish the terms as follows. Arousal refers to " … a nondirective generalized bodily activation (…) and is thought to range from a comatose state to a state of extreme excitement as might be manifested in a panic attack" (p. 129). In contrast to arousal, which is nondirective, having either beneficial or detrimental effects on performance (e.g., Wann, 1997), anxiety is seen as directional in that it is an unpleasant emotional state (e.g., Woodman & Hardy, 2001). In other words, "anxiety is by definition a negative feeling state" (Jones & Hanton, 2001, p. 393). Anxiety occurs as a result of threat (Schwenkmezger & Steffgen, 1989) and this threat is "related to the subjective evaluation of a situation, and concerns jeopardy to one's self-esteem during performance or social situations, physical danger, or insecurity and uncertainty" (Schwenkmezger & Steffgen, 1989, pp. 78-79). Thus, anxiety has a mental element (e.g., worry, apprehension), which is called cognitive anxiety, and a physiological element that matches the construct of arousal as defined above and is called somatic anxiety (Martens, Vealey, & Burton, 1990) or physiological arousal (Woodman & Hardy, 2001). Finally, stress is seen as a result of demands placed on the individual that are perceived to exceed available coping abilities (e.g., Janelle, 2002; Selye, 1976). Depending on one's interpretation of the environmental demands stress will be conceived as positive, negative, or neutral. The negative form of stress is called distress or anxiety and can have detrimental effects on performance (Wann, 1997).

In the present study we will focus on the impact of anxiety on *movement* behaviour to gain further insight into the anxiety-performance relationship and to explore the mechanisms underlying this relationship. To explain the (debilitative) effects of anxiety and the relation between anxiety and movement behaviour, research has resorted to the underlying attentional mechanisms: Influences of state anxiety on performance are assumed to be related to changes in attention and concentration (Janelle, 2002; Landers, 1980; Nideffer, 1976, 1981). Consequently, in the course of time, several attentional models have been put forward in the literature. The models are based on the assumption that for successful performance one should attend to task-relevant information while ignoring task-irrelevant information (Lewis & Linder, 1997). Broadly, the models can be classified in either distraction models or self-focus models (see Beilock & Carr, 2001; Lewis & Linder, 1997; Mullen & Hardy, 2000).

Distraction models propose that some stimuli (e.g., anxiety) shift attention away from task-relevant information to distracting, task-irrelevant cues (either externally or internally), thereby decreasing performance (see Beilock & Carr, 2001; Lewis & Linder, 1997; Mullen & Hardy, 2000). For example, Wine's (1971) distraction model draws upon a difference in attentional focus of high- and low-(test-)anxious persons during task performance to explain (debilitating) effects of anxiety on performance. Highly test-anxious persons often divide their attention between task-irrelevant (i.e., self-evaluative worry) and task-relevant variables whereas low-test-anxious persons focus their attention more fully on the task.

The self–focus models state that pressure and anxiety raise self-consciousness and evoke an inward focus of attention (Baumeister, 1984; Masters, 1992). The increased inward attention might induce a conscious step-by-step control of movement execution disrupting the normal, automatic processing of the task at hand and leading to a decrease in performance (Baumeister, 1984; Beilock & Carr, 2001; Lewis & Linder, 1997). Masters (1992) called this the 'conscious processing hypothesis' (see also Masters, 2000; Masters, Polman, & Hammond, 1993). The proposed anxiety-induced renewed conscious control may reflect a temporary regress to a lower skill level or an earlier stage of learning (Baumeister, 1984;

Beilock, Carr, MacMahon, & Starkes, 2002; Beilock, Wierenga, & Carr, 2002; Masters, 1992, 2000; Mullen & Hardy, 2000; Pijpers, Oudejans, Holsheimer, & Bakker, 2003). Such a regress implies more cognitive control of movements, as is also found in earlier stages of learning (Fitts & Posner, 1967). This is supposed to be detrimental to skilled performance as it interferes with the well-learned automatisms of the skill.

In the present study, we will mainly draw upon Masters' (1992) conscious processing hypothesis as it holds some promise with respect to explaining influences of anxiety on *movement* behaviour.[1] The last decade, several research groups have provided empirical support for the conscious processing hypothesis, especially with respect to golf putting (Beilock & Carr, 2001; Beilock, Carr, et al., 2002; Beilock, Wierenga, & Carr, 2002; Hardy, Mullen, & Jones, 1996; Lewis & Linder; 1997; Masters, 1992; Mullen & Hardy, 2000), but also the more continuous task of soccer dribbling (Beilock, Carr, et al., 2002). However, so far these studies concerned the testing of the relationship between pressure and performance (Beilock & Carr, 2001; Hardy et al., 1996; Lewis & Linder; 1997; Masters, 1992; Mullen & Hardy, 2000) as well as between the proposed attentional mechanisms and performance (as end product; Beilock, Carr, et al., 2002). Research into the relation between anxiety and movement behaviour is scarce.

Following the conscious processing hypothesis it is assumed that under the influence of anxiety movement behaviour will have characteristics that are typically found in early stages of motor learning. Movements in early learning are uncertain, confused, and clumsy (Bernstein, 1996). More specifically, learning a skill is accompanied by irregular, jerky, less fluent, and slow movements requiring much effort (Beilock & Carr, 2001; Beilock, Carr, et al., 2002; den Brinker & van Hekken, 1982; den Brinker, Stäbler, Whiting, & van Wieringen, 1986; Magill, 1998; Masters, 1992; Vereijken, van Emmerik, Whiting, & Newell, 1992; Vincken & Denier van der Gon, 1985; Whiting, Bijlard, & den Brinker, 1987). In addition, movements in early learning are found to be restricted in amplitude (den Brinker et al., 1986; Vereijken, Whiting, & Beek, 1992).

Beuter and Duda (1985), Collins et al. (2001), and Weinberg and Hunt (1976) provided evidence that under the influence of anxiety performance was characterized by less fluent movements. In a previous study we investigated the effects of anxiety on movement behaviour of participants executing a complex whole-body task, namely, climbing a traverse on an artificial climbing wall (Pijpers et al., 2003; see also Chapter 2). By building traverses at different heights on the wall anxiety was manipulated in an ecologically valid situation that

[1] In this regard, the 'processing efficiency theory' (Eysenck & Calvo, 1992), popular in recent sport scientific literature (e.g., Hardy & Jackson, 1996; Janelle, 2002; Mullen & Hardy, 2000; Smith, Bellamy, Collins, & Newell, 2001; Woodman & Hardy, 2001), seems less suitable as its main emphasis is on the relation between anxiety and performance outcome, rather than movement behaviour.

was both safe and frightening (Baddeley, 1972; Idzikowski & Baddeley, 1987). We could hereby examine anxiety effects ‘in-event’ (Collins et al., 2001), while applying an intraindividual design to enhance power to identify changes in the dependent variable of interest (i.e., movement performance) (Jones, 1995a). We found that high on a climbing wall (i.e., under high-anxiety conditions), participants climbed less efficiently than low on the wall (Pijpers et al., 2003). In addition, we found longer climbing times and a less fluent displacement of the body’s centre of gravity when participants were anxious, as would be expected on the basis of the conscious processing hypothesis.

Although longer climbing times were expected, the results of our study (Pijpers et al., 2003) remained mute as to why participants’ climbing times increased so much (by almost 50%) and about what exactly happened with participants’ limb movements underlying the decrease in fluency of the displacement of the body’s centre of gravity. For instance, did participants make more limb movements? Did they grasp the holds longer? Did they move slower from hold to hold? In the present study we investigated these questions with two experiments to further test Masters’ (1992) conscious processing hypothesis and gain more insight into the anxiety-performance relationship by focusing on changes in movement execution.

Experiment 1

The purpose of Experiment 1 was to examine anxiety-induced changes in movement behaviour. We asked participants to perform a climbing task low (low-anxiety condition) and high (high-anxiety condition) on a climbing wall. No time constraints were imposed. Following the conscious processing hypothesis (Masters, 1992) we expected that participants would make more movements under anxiety conditions. Gibson (1988) distinguished ‘exploratory actions’ and ‘performatory actions’, where exploratory actions are primarily information-gathering actions (e.g., when a climber just wants to find out whether he or she can reach a particular hold). Performatory actions are executive actions meant to reach a certain goal (e.g., moving a hand from one hold to the next in order to use it as support).

Because in early learning movements are more uncertain, and the learner executes more exploratory movements (e.g., Gibson, 1988; Gibson & Spelke, 1983; Newell & McDonald, 1992; Von Hofsten, 1990), we also expected more exploratory movements when climbing high than when climbing low on the wall. In addition, as we expected that movements would have smaller amplitudes under anxiety conditions, we expected that participants would use more holds—that is, make more performatory movements—when climbing high on the wall than when climbing low on the wall. Therefore, compared to the traverse we used in our earlier study (Pijpers et al., 2003; see also Chapter 2), we now added two extra holds that were not strictly necessary to perform the climbing task. Together, the expected anxiety-related changes in the number of exploratory and performatory movements would at least partly explain the longer climbing times that were found by Pijpers et al.

Method

Participants

A total of 8 male participants, mean age 31.4 years (*SD* = 4.81) volunteered to participate in the experiment. The participants had no experience in climbing and were naive to the purposes of the experiment.

The Dutch version of the A-Trait scale of the State-Trait Anxiety Inventory (STAI)[2] was used as a standard check to measure trait anxiety (Spielberger, Gorsuch, & Lushene, 1970; van der Ploeg et al., 1979). The mean trait anxiety score for the participants was 31.9 (*SD* = 6.24) and was not significantly different from the mean score for Dutch male college students (*M* = 36.1) obtained by van der Ploeg, Defares, and Spielberger (1980), $t(7) = 1.90$, *ns*, *t* test between a sample and a population mean (Thomas & Nelson, 1996). The results indicate that the participants had no extraordinary tendency to respond to situations perceived as threatening with an elevation in state anxiety (e.g., Smith, Smoll, & Wiechman, 1998).

Experimental Set-up

Participants climbed on a vertical climbing wall (width: 3.5 m; height: 7.0 m; see Figure 3.1), which was placed in a gym-sized laboratory. The wall had a grey grainy texture for friction. Holds of varying shape and size could be bolted on the wall at relative distances of about 0.20 m.

On the wall, two identical, horizontal routes (so-called ‘traverses’, built by a professional route designer) were mounted (see Figure 3.1). Each traverse consisted of six footholds and seven handholds of varying size and shape, which were all suitable for novice climbers. Holds 12 and 13 (see Figure 3.1) were labelled ‘additional holds’ because these holds were not necessary to climb the traverse successfully as was shown in a previous study (Pijpers et al., 2003). The mean height of the footholds of the low traverse was 0.4 m (*low* condition); the mean height of the footholds of the high traverse was 5.0 m (*high* condition). To be able to start with the high traverse in the same physical condition as in the low traverse, a movable platform, 5.0 m above the floor, was placed 1.2 m in front of the climbing wall.

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[2] The STAI A-Trait scale is a self-report questionnaire that measures anxiety proneness—that is, the tendency to respond to situations perceived as thrilling with an elevation in state anxiety intensity. Scores range from a low of 20 to a high of 80. Normative data for the STAI A-Trait scale depict a mean score of 36.1 (*SD* = 8.4) for male college students and of 37.7 (*SD* = 8.4) for female college students (van der Ploeg, Defares, & Spielberger, 1979).

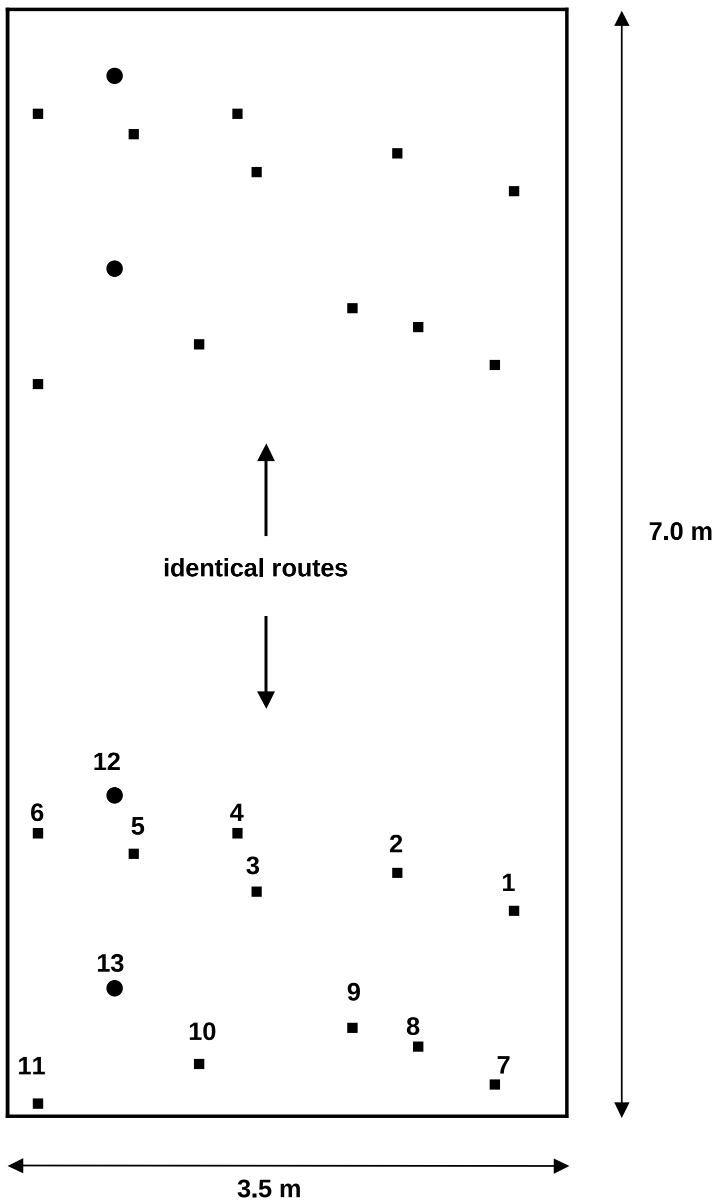

Figure 3.1. *Front view of the climbing wall used in Experiments 1 and 2. The additional holds (Holds 12 and 13) used in Experiment 1 are indicated by '●'. The routes in the low and high condition are identical.*

The participants wore well-fitting climbing shoes (Enduro 954, La Sportiva). In both conditions participants wore an integral harness (Edelrid). We used the so-called 'top-roping' technique to ensure the safety of the participants. Top–roping involves 'paired' climbing (Skinner & McMullen, 1993)—that is, one end of the rope is tied onto participants' harness, the safety rope runs up around a solid iron bar at the top of the climbing wall, and back to the ground. This end of the safety rope runs through the belay device on the belayer's harness. The belayer is the person who is managing the safety rope and preventing and protecting participants from falling down if they lose grip on the wall (Skinner & McMullen, 1993).

State anxiety was assessed by means of the 'anxiety thermometer' validated by Houtman and Bakker (1989). The anxiety thermometer is a 10-cm continuous scale on which participants were asked to rate their anxiety feelings at a particular moment, ranging from 0 (*not anxious at all*, the left end) to 10 (*extremely anxious*, the right end). Participants had to place a cross on the 10-cm scale to indicate how they felt at a particular moment. The distance between the left end and cross (in cm) was used as a measure of the reported anxiety. Consequently, it is a quick way to measure state-anxiety in contrast to the often-used Competitive State Anxiety Inventory-2 (CSAI-2, Martens et al., 1990), which would be unsuitable for our purposes (see also Pijpers et al., 2003). For each measurement, a separate anxiety thermometer was used.

During climbing we recorded heart rate values every 5 seconds using a Sporttester (Polar Electro-3000). Afterwards, for every climb the mean heart rate was calculated.

Movements of the participants were recorded using two S-VHS camcorders at a sampling rate of 50 Hz. One camcorder was placed on the floor to get an overall view of the experimental set-up and one (movable) was used to get a clear picture of the movements of hands and feet. Two experimenters handled the camcorders. The videotapes were copied, and a Vertical Interval Time code (VIT code, a unique time code) was added using an Alpermann & Velte Time Code 30 generator. We used a video frame grabber and a digitizing program to determine the climbing times.

Procedure

Participants were tested individually and on one day. Participants were informed about the procedure of the experiment after which they signed a statement of informed consent. They completed the Dutch version of the STAI A-Trait scale (van der Ploeg et al., 1979) and filled out an anxiety thermometer (to familiarize them with the thermometer).

To make participants familiar with the climbing task a videotaped example of an experienced climber was shown. The climber demonstrated an efficient way to climb the traverse. A Sporttester was placed, and participants put on their climbing shoes and harness. They then practised the (low) traverse until they were able to climb the traverse two times back and forth properly and easily. Practice periods lasted from 5 to 10 minutes. After practising participants were allowed 15-20 minutes to fully recuperate.

Subsequently, participants were asked to take position on the wall: Participants placed their right hand on Hold 1 (see Figure 3.1), left hand on Hold 2, right foot on Hold 7, and left foot on Hold 8 ('starting position'). As soon as participants had taken position on the wall in the high condition the platform was quickly removed to prevent the risk of striking the platform. In the low condition, participants were instructed not to start climbing immediately, but to wait just as long as it would have taken to relocate the platform (less than 10 s). In both conditions participants started climbing at a sign from one of the experimenters.

In each condition, participants climbed two times. Starting at the right side of the wall participants climbed to the left side of the wall and then returned to the right side of the wall followed by a five-minute break. After climbing in the high condition, participants stepped back on the platform. Next, participants climbed the other condition (high if they had started low, low if they had started high). Participants were then allowed a recuperation time of 20 minutes. Then the procedure of the first two climbs was repeated. Whether participants started low or high changed with every new participant. After each time participants had climbed, they had to rate their feelings of anxiety by means of the anxiety thermometer. Participants were asked to recall how anxious they had felt during climbing. The mean of the two anxiety scores (after the first and second climb in a condition) was used as an anxiety score for that condition. Participants were asked to climb as fast yet as safe as possible. It was emphasised that participants' first goal should be to complete the climbing task without falling. None of the participants fell during the experiment. In total, only six times did a participant slip from a foothold, without further consequences as the participants could recover easily from these slips. Three slips were made in the low-anxiety condition and three in the high-anxiety condition.

One of the experimenters served as belayer. In the low condition, the belayer acted as insurance that both conditions were similar for the climber. Participants were informed before beginning the climb in the low condition (mean height of the footholds: 0.4 m) that, despite the belayer, if they slipped they should break their fall themselves, as the safety procedure would not be effective so low above the ground.

Dependent variables

Per condition the following dependent variables were determined from the videotapes:

1. *Number of explorative movements*, defined as the number of times a hold was touched without it being used as support.

2. *Number of performatory movements*—that is, the number of movements made during climbing; a movement was defined as releasing a hold and making contact with another hold *and* using that hold as support.

3. *Use of additional holds*, defined as the number of times the additional holds (Holds 12 and 13; see Figure 3.1) were used during climbing.

Participants' movements were viewed by two independent raters for accurate determination of the dependent variables mentioned above. In all cases the raters agreed on the number of performatory movements, the number of explorative movements, and the number of times the additional holds were used.

4. *Climbing time* was also registered for each condition; it was defined as the sum of the

time needed to climb the first and second climb in a condition. As soon as participants released one of the holds in the starting position, time started. When participants had returned to the starting position, the time was stopped.

Statistical analysis

The effect of height (low condition, high condition) was tested using several paired t tests (one-tailed) for the dependent variables mentioned above. Effect sizes of within factor (ES_w) were calculated to provide an estimation of the meaningfulness of a difference between two means (Mullineaux, Bartlett, & Bennett, 2001; Thomas & Nelson, 1996). An effect size of 0.2, 0.5, and greater than 0.8, represents small, moderate, and large differences, respectively (Cohen, 1988).

Results

State anxiety and heart rate

To determine whether the anxiety manipulation was successful we performed a paired t test on the anxiety thermometer data. Averaged over the two climbs participants reported significantly higher anxiety scores in the high condition than in the low condition, $t(7) = 3.46$, $p < .005$, $ES_w = 4.72$; the mean score on the anxiety thermometer in the high condition was 2.7 ($SD = 1.90$), and in the low condition 0.7 ($SD = 0.43$).

Averaged over two climbs per condition the mean heart rate differed significantly between conditions, $t(7) = 3.69$, $p < .05$, $ES_w = 1.45$, heart rate being higher in the high condition (M = 157.3 beats per minute, bpm, $SD = 14.63$) than in the low condition (M = 143.3 bpm, SD = 9.66). Both measures pointed to a successful manipulation of anxiety—that is, in the high condition participants were more anxious than the low condition.

Behavioural variables

Table 3.1 shows the dependent variables for the low and the high condition. It appeared that climbing time increased significantly and by more than 50%, from 56.6 s in the low condition to 89.5 s in the high condition, $t(7) = 3.55$, $p < .05$, $ES_w = 0.96$. There were large individual differences in climbing time causing the large standard deviations. In the low condition climbing time ranged from 28 to 141 s, and in the high condition from 30 to 182 s. Note that the longer climbing time may partly explain the higher heart rates.

The number of explorative movements was significantly higher in the high condition than in the low condition, $t(7) = 1.99$, $p < .05$, $ES_w = 1.58$. The longer climbing time cannot be explained by a significant increase in number of performatory movements since the number of performatory movements did not statistically differ between the low and high condition, $t(7) = 0.71$, $p = .25$. Furthermore, no significant difference was found between the low and high condition for use of additional holds, $t(7) = 0.27$, $p = .40$.

Table 3.1. *Climbing time[a], number of explorative movements, number of performatory movements, and use of additional holds for the conditions in Experiment 1.*

	Condition			
	Low anxiety		High anxiety	
Variable	*M*	*SD*	*M*	*SD*
Climbing time	56.6	34.18	89.5	46.51
Number of explorative movements	2.5	2.45	6.4	4.70
Number of performatory movements	54.1	9.52	56.6	7.34
Use of additional holds	4.4	2.99	4.7	2.69

[a]In s.

Discussion

In Experiment 1 we investigated manifestations of anxiety in movement behaviour via changes in number of exploratory movements, the number of performatory movements, and the use of additional holds. In addition, we calculated climbing time. The differences in climbing time in the low and high condition clearly revealed that participants' movement behaviour differed in both conditions. The increase in climbing time could be explained in part by an increase in the number of explorative movements, but not by an increase in the number of performatory movements or by the use of additional holds.

The substantially longer climbing time in the high-anxiety condition seems to be a robust finding as it replicates the results of our previous study (Pijpers et al., 2003; see also Chapter 2). Together with the increase in explorative movements the longer climbing time showed that anxiety indeed changed participants' movement behaviour, which is in line with Masters' (1992) conscious processing hypothesis as well as with earlier results of Weinberg (1978; Weinberg & Hunt, 1976), Beuter and Duda (1985; Beuter et al., 1989), and Collins et al. (2001) who also found changes in movement behaviour associated with anxiety.

Anxiety had no significant effects on the total number of performatory movements made and on the number of times the extra holds were used. In retrospect, the number of holds on the wall probably did not leave enough room for many alternatives—that is, for an increase in the number of holds used. The number of holds constrained the number of possible movement solutions too much to find differences in the number of movements between conditions. It also appeared that in the low condition participants also made use of the additional holds making *extra* use in the high condition hardly possible.

Note that, although statistically significant between conditions, the average anxiety scores were rather low. In both conditions the current scores were about half the scores of Pijpers et al. (2003) who used the same climbing wall and about the same traverse (see also Chapter 2). In the present experiment, participants had to climb twice in each condition. After the first climb in the high condition, participants stepped back on the platform and returned to the floor area. This procedure had a considerable diminishing impact on the average anxiety scores as participants experienced that nothing seriously happened to them. This is reflected in the anxiety thermometer scores: The first time participants had climbed in the high condition the average score on the anxiety thermometer was 3.5 (SD = 2.46), the second time only 2.0 (SD = 1.84).

An issue to pursue is where the substantially longer climbing time in the high condition than in the low condition comes from as the increase in the number of explorative movements can only explain a small part of the longer climbing time. We addressed this issue in Experiment 2.

Experiment 2

In search for an explanation for the considerably longer climbing time in the high condition, in Experiment 2 we not only measured the number of exploratory and performatory movements, but also the temporal aspects of these movements—that is, how long participants grasped the holds in both conditions and how fast they moved from hold to hold. Temporal changes in movement patterns may point to an anxiety-induced renewed conscious control of movements as is to be expected from the conscious processing hypothesis (Masters, 1992; Mullen & Hardy, 2000). Recall, that in this model anxiety is assumed to evoke an inward focus of attention on the execution of movements. This inward focus of attention and subsequent step-by-step control of movements is proposed to slow down the execution of sensorimotor skills (Beilock & Carr, 2001; Beilock, Carr, et al., 2002; Mullen & Hardy, 2000). As the cognitive processes involved will take more time than a more automated execution of the task, we expected a longer preparation of movements (i.e., longer contact times with the holds) as well as slower execution of the movements (i.e., slower movements from hold to hold) under high-anxiety compared to low-anxiety conditions.

The design and procedure of Experiment 2 were largely similar to those of Experiment 1. However, two major methodological changes had to be made. First, to give us the opportunity to investigate the temporal aspects of movement execution, special technical adjustments to the holds were made (for more details, see *Method* of Experiment 2). Second, in each condition participants had to climb the traverse two times back and forth without a break instead of with a break as was done in Experiment 1. We considered the break to be too harmful for our anxiety manipulation (see *Discussion* of Experiment 1). Given the main purpose of Experiment 2, it was important that participants completed four traverses in the low as well as the high condition to obtain sufficient data to make statistical analysis sensible.

Method

Participants

A total of 15 participants, 13 male and 2 female, mean age 20.7 years (*SD* = 2.22), volunteered to participate in the experiment. None of them had participated in Experiment 1. The participants, all college students, had no experience in climbing.

The mean trait anxiety score for the male participants was 35.8 (*SD*= 10.98), and for the (two) female participants 33.5 (*SD*= 3.54). The mean score of the male participants was comparable with the mean score for Dutch male college students (*M* = 36.1) obtained by van der Ploeg et al. (1980), $t(12) = 0.10$, *ns*, *t* test between a sample and a population mean (Thomas & Nelson, 1996). The two female participants were less trait anxious compared to Dutch female college students (*M* = 37.7, the 95% confidence interval ranges from 36.5 to 38.7, van der Ploeg et al., 1980). As in Experiment 1, the results indicated that the participants had no extraordinary predisposition to respond across many situations with high levels of state anxiety (e.g., Smith et al., 1998).

Experimental Set-up

Participants climbed on the same climbing wall as in Experiment 1 in a low and high condition. Again, two identical, horizontal routes (traverses) were mounted on the wall, each consisting of five footholds and six handholds (see Figure 3.1). We removed the additional holds (Holds 12 and 13) used in Experiment 1, as including them did not provide additional information with respect to participants' movement behaviour. Due to the equipment needed to register the contact time between a hand and a hold and between a foot and a hold (see below) it was necessary to slightly change the positions of the holds. The mean height of the five footholds of the low traverse was 0.3 m (*low* condition); the mean height of the five footholds of the high traverse was 4.9 m (*high* condition). To enable participants to begin the climb on the wall in the same physical condition as in the low traverse, again the movable platform was used. The platform was positioned at a distance from the wall calculated as 1.5 times the length from a participant's arm. Tests prior to the experiment established that if participants fell while climbing the high traverse, this was a distance at which they were at no risk of striking the platform. Therefore, it was not necessary to replace the platform, and participants could start climbing when they were ready. Participants in the high condition were assisted in crossing over this platform prior to climbing, and they were held by one of the experimenters until they indicated that they were ready to start. In the low condition this situation was simulated by asking participants to begin from behind a line marked clearly on the floor. The line was positioned at the same distance from the wall as the platform in the high condition. In the low condition it was not considered necessary to support the participants. Instead, an experimenter stood behind them and indicated that they should begin when they were ready.

Each hold on the climbing wall was equipped with on/off switches (see Figure 3.2). Vertical pressure from the climber's foot activated the switch (threshold 2-5 N). The handholds could be activated in the vertical as well as horizontal direction. Pressure from the participant's foot or hand activated a signal to the personal computer. Releasing pressure from the hold resulted in deactivating the switch. This equipment made it possible to determine the time of hand-hold contact and the time of foot-hold contact and, hence, the time participants moved from one hold to the other, as well as the total climbing time, with an accuracy of 1-5 ms (see also later under *Dependent Variables*).

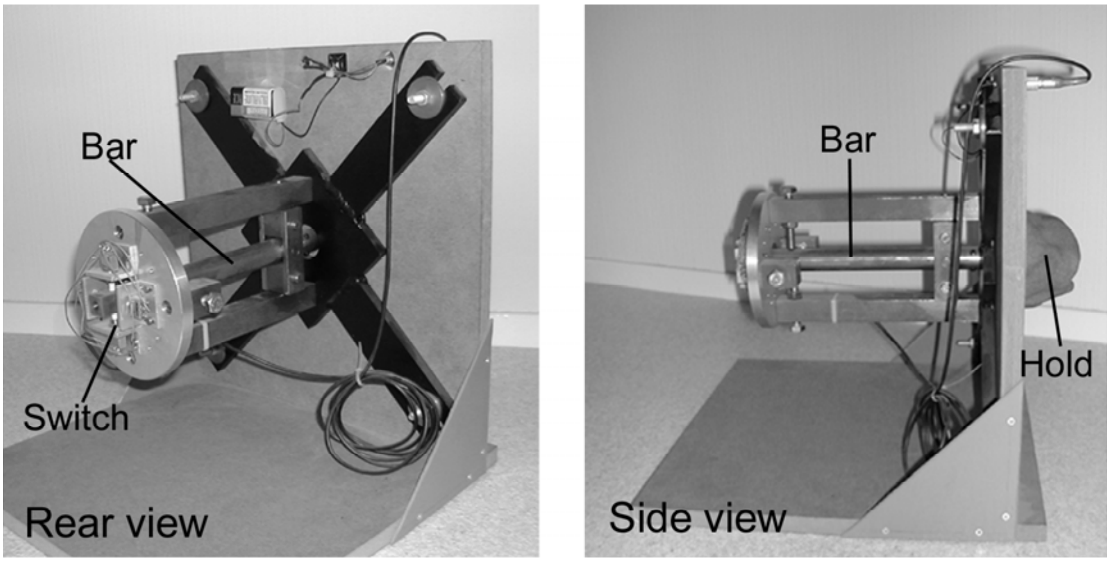

Figure 3.2. *Model of (hand)hold-time registration mechanism. All holds on the climbing wall were equipped with such a time registration mechanism. The hold was connected with a bar that went through the climbing wall (see right panel). Pressure from participant's hand or foot activated one of the switches, causing a signal to the computer. The handholds could be activated in the vertical as well as horizontal direction (see left panel), the footholds only in vertical direction. Releasing pressure from the hold resulted in deactivating the switch.*

As in Experiment 1 participants wore well-fitting climbing shoes and an integral harness connected to a climbing rope. The same security procedure as that in Experiment 1 was used. The wall was screened from public view by black plastic sheeting. At the top, the sheeting was connected to the movable platform and extended outward and downward to the floor in the shape of a tent, approximately 3 m from the wall. All climbs were videotaped using an S-VHS camcorder (sampling rate of 50 Hz). In the low condition, the camcorder was in a fixed position behind and above the climber. The fixed position monitored all the hand- and footholds. Participants' hand and foot movements were clearly visible. In the high condition, an experimenter standing on the elevated platform held the camcorder and moved with participants to record participants' movements. State and trait anxiety and heart rate were measured in the same way as in Experiment 1.

Task Execution

As in Experiment 1 participants were asked to climb as fast yet as safe as possible but it was stressed that participant's first goal was to complete the climbing task without falling. They were told that a fall would immediately end the experiment. During the experiment, none of the participants fell. In case of a fall, the trial would neither be completed nor re-run, but the participant would be excluded from the experiment and experimental analyses. When participants make a fall, they experience that they run no risk. Consequently, climbing the high traverse once more would be experienced as much less anxiety provoking. One participant almost fell during the fourth traverse in the high condition but could recover without support from the safety rope and complete the task. Two participants once slipped off a foothold with one foot, both in the low condition.

Procedure

Before the day of the experiment, all participants completed the STAI A-Trait inventory in the presence of one of the experimenters. Participants were tested individually on the next day. Their total involvement in the experiment was approximately two hours. The entire procedure was explained to each participant. Participants were then asked to read and sign a statement of informed consent. Participants were not informed that climbing time was one of the variables being measured.

After changing into sport clothing, each participant was fitted with climbing shoes and given the opportunity to practise on the wall. As debriefing sessions in Experiment 1 made clear that the videotaped climbing example was not very helpful in task execution we only gave verbal instructions in Experiment 2. When necessary general, non-technical instructions were given to participants, for example 'use your legs' to prevent them becoming too tired and not being able to complete the climbing task. No specific instructions were given on how to climb faster or to execute movements. Practice periods lasted from 5 to 10 minutes and stopped when participants were able to successfully complete the traverse on the wall four times without a pause (see also below). This opportunity to practise prior to the experiment was given to all participants. It allowed the experimenters to be confident that a participant's failure to complete the task in either condition would not be due to lack of experience with the task.

Following the practice period, the Sporttester was placed. The watch indicating the recorded number of beats was attached to the belt behind participants' back to prevent it from being read by the participant. Participants were then taken outside the screened off area and allowed 30 minutes to fully recuperate.

Approximately 10 minutes before each condition (high and low conditions were counterbalanced), participants were brought back to the wall and seated, either on the platform or the floor, depending on condition. Two minutes before the climb participants were asked to indicate how anxious they were at that moment by completing the anxiety thermometer (to familiarize them with the thermometer). Then, participants were led to the wall and connected to the rope. The Sporttester was switched on, and participants were instructed to begin when ready. The computer began recording when participants had both hands and both feet on the wall (right hand on Hold 1, left hand on Hold 2, right foot on Hold 7, and left foot on Hold 8, see Figure 3.1). This was the starting position. Time was stopped when participants had resumed the starting position after participants had climbed the traverse four times—that is, starting at the right side of the wall the participants climbed to the left side (first traverse), then returned to the right side (second traverse), again to the left side (third traverse), and again back to the right side of the wall (fourth traverse).

Immediately after each condition, participants were asked to recall how anxious they had felt *during* climbing and to record this on the anxiety thermometer scale. This was used as anxiety score for that condition.

Participants were allowed a recuperation period of between 30 and 40 minutes before starting the second condition. During this period, they were brought outside the screened area and offered refreshments. They were not encouraged to talk about the climb. If participants mentioned the experience, one of experimenters would respond in a general way to the remark and then endeavour to change the subject. No information about the recordings that were taken was given to the participants. If they asked questions, they were told that on completion of the experiment all questions would be fully answered. The second condition was executed in a similar fashion as the first, but now participants climbed in the other condition (low if they had started high, high if they had started low).

Dependent variables

The equipment used in this experiment made it possible to determine with great accuracy a number of dependent variables. To visualize the movement patterns of each participant, all the participant's climbing movements were coded on a sheet (for an example, see Figure 3.3). This made it easier to determine the number of movements, when a particular movement started and ended, how long a hold was grasped, and so on.

First, to make a direct comparison with the results of Experiment 1 possible, the dependent variables climbing time (and two dependent variables related to climbing time, namely traverse time and rest between traverses), number of explorative movements, and number performatory of movements were determined.

1. *Climbing time* was defined as the time needed to climb the traverse four times. Time started as soon as participants had left the starting position and stopped as soon as participants

had resumed the starting position after climbing the traverse four times.

2. *Traverse time* was defined as the time needed to climb one traverse—that is, for the first and third traverse the period between releasing one of the Holds 1, 2, 7, or 8 (starting position) and making contact with Hold 6 (left hand), Hold 5 (right hand), Hold 11 (left foot), and Hold 10 (right foot; end position; see Figure 3.1). The time to climb the second and fourth traverse was defined as the period between releasing one of the Holds 5, 6, 10, or 11 and returning to the starting position at the right side of the wall.

3. *Rest between traverses* was defined as the duration of the breaks between traverses: thus, from reaching the starting position or end position until initiation of the first movement away from that position.

4. *Number of explorative movements* and *number of performatory movements* (see Experiment 1 for a definition of these variables). The time constraint for an exploratory movement was that it had to last at least 500 ms—that is, the hold from where it started had to be released minimally 500 ms before the hand or foot returned to this hold again (with or without touching another hold). Otherwise it was not considered an exploratory movement.

Second, we calculated the total contact times with the holds (*total contact time*) as well as those for feet and hands separately (*total contact time feet* and *total contact time hands*, respectively). In the first instance, this was done irrespective of movement pattern (i.e., which holds were used and in which sequence), which could, of course, have been different in the high and low conditions. *Total contact time* was defined as the sum of all contact times of all holds for each participant (thus, *total contact time feet* + *total contact time hands*).

Third, we determined the average movement times from hold to hold (*average movement time*) both for the feet (*average movement time feet*) and the hands (*average movement time hands*); again this was done irrespective of movement pattern.

Fourth, we analysed contact time and movement time of a selected number of (sequences of) movements that were similar in the low and high condition, hereby correcting for possible differences in movement patterns that may have played a role in the other analyses.

Statistical analysis

As in Experiment 1 several paired *t* tests were executed. When necessary, two-factor repeated measures ANOVAs were used. Eta squared (η^2) assessed the explained variance in the ANOVA models. Pair-wise comparisons using *t* tests were made using the Bonferroni correction procedure (Kinnear & Gray, 2000) to identify specific mean differences when a significant main effect was found. The *p* values that are reported on the basis of this Bonferroni method are scaled to the .05 alpha level, so that, as usual, *p* values smaller than .05 indicate a significant effect.

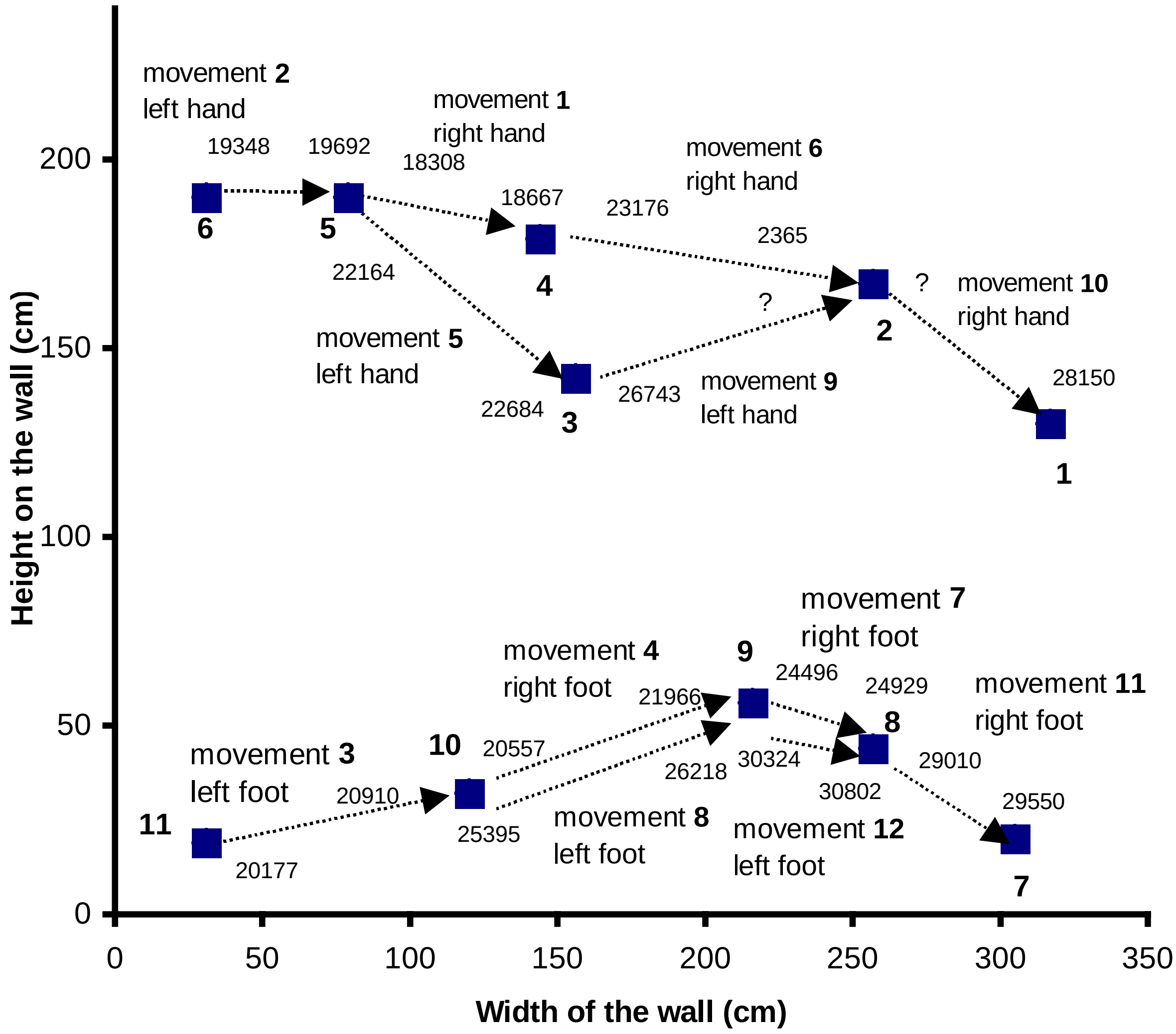

Figure 3.3. *Typical example of how the route was climbed. Shown here is the second traverse (low condition). The black squares indicate the positions of the holds. The times the movement started and stopped are indicated above or below the arrow (left: time the movement started, in ms; right: time the movement ended, in ms). The question mark at the end of Movement 9 (left hand) indicates that it was not possible to determine the time Movement 9 ended because Hold 2 was already activated by the right hand (Movement 6). Likewise, it was not possible to determine the start of Movement 10 (also indicated by a question mark) because the left hand still activated Hold 2.*

Results

Anxiety scores and heart rate

Participants reported significantly higher anxiety scores in the high condition (M = 6.5, SD = 2.38) than in the low condition (M = 3.4, SD = 1.96), $t(14) = 5.24$, $p < .001$, $ES_w = 1.60$. The mean heart rate appeared to be higher in the high condition (M = 145.9 bpm, SD = 19.30) than in the low condition (M = 126.3 bpm, SD = 18.37), $t(13) = 4.01$, $p < .001$, $ES_w = 1.07$. (Due to a technical problem one of heart rate measurements was missing.)

The results indicated that the anxiety manipulation was again successful: In the high condition state anxiety was higher than in the low condition.

Climbing time, traverse time, rest between traverses, number of explorative movements, and number of performatory movements

An overview of the results concerning climbing time, traverse time, rest between traverses, number of explorative movements, and number of performatory movements (hand and foot movements) is presented in Table 3.2. As in Experiment 1 and our previous study (Pijpers et al., 2003; see also Chapter 2), the climbing time in the high condition was significantly longer (about 22%) than in the low condition, $t(14) = 4.59$, $p < .001$, $ES_w = 1.17$. A 2 (height: low condition, high condition) × 4 (traverse: Traverse 1-4) repeated measures *ANOVA* on the traverse time data also revealed a significant main effect of height, $F(1, 14) = 26.00$, $p < .001$, $\eta^2 = .65$, confirming that the average traverse time was longer in the high condition than in the low condition. The main effect of traverse did not reach the 5%, but the 10%, significance level, $F(3, 43) = 2.39$, $p < .10$, $\eta^2 = .15$. Participants tended to climb faster in the fourth traverse (M = 14.77 s, SD = 2.907) than in the first traverse (M = 16.43 s, SD = 3.759), second traverse (M = 16.48 s, SD = 2.820), and third traverse (M = 16.54 s, SD = 2.360). The Bonferroni t tests for making comparisons among the means of the traverse time data showed that participants climbed the fourth traverse significantly faster than the second traverse ($p < .05$). The interaction between height and traverse was not statistically significant, $F(3, 42) = 0.74$, $p = .54$.

The analysis of the variable rest between traverses produced no significant effect, $t(14) = 0.44$, $p = .33$, hence the breaks between traverses did not contribute to the longer climbing times in the high condition. As in Experiment 1 the number of explorative movements was significantly higher in the high condition than in the low condition, $t(14) = 1.87$, $p < .05$, $ES_w = 0.66$. Also, in line with the results of Experiment 1, the number of performatory movements was not significantly different in the low and high condition, $t(14) = 0.86$, $p = .20$. Investigating foot and hand movements separately, it appeared that more foot movements were made in the high condition than in the low condition, though the difference was not significant, $t(14) = 1.75$, $p < .10$, $ES_w = 0.36$. The number of hand movements was not significantly different between conditions, $t(14) = 0.92$, $p = .19$.

To summarize, again climbing time was considerably longer in the high condition than in the low condition, which can partly be explained by more explorative movements and perhaps more foot movements. Participants did not take more rest between traverses, and the total number of performatory movements was not significantly different in both conditions.

Table 3.2. *Climbing time[a], traverse time[a], rest between traverses[a], number of explorative movements, number of performatory movements, number of foot movements, and number of hand movements for the conditions in Experiment 2.*

	Condition			
	Low anxiety		*High anxiety*	
Variable	*M*	*SD*	*M*	*SD*
Climbing time	62.13	11.987	76.09	11.032
Traverse time				
Traverse 1	15.11	3.603	17.75	5.100
Traverse 2	14.16	3.649	18.81	3.541
Traverse 3	14.77	3.282	18.32	3.428
Traverse 4	13.30	3.530	16.23	3.320
Rest between traverses	4.81	1.374	4.98	2.017
Number of explorative movements	1.2	1.21	2.0	1.60
Number of performatory movements	49.6	6.14	50.3	4.11
Foot movements	21.9	3.16	23.0	2.36
Hand movements	27.7	3.58	27.3	2.94

[a]In s.

Contact times and movement times (irrespective of movement pattern)

Table 3.3 presents the results of the time hands and feet made contact with the holds—that is, total contact time, total contact time feet, and total contact time hands irrespective of movement pattern (i.e., which holds were used and in which sequence). The total contact time in the high condition was significantly longer than in the low condition, $t(14) = 5.40$, $p < .001$, $ES_w = 1.23$. In addition, total contact time feet, as well as total contact time hands, was significantly longer in the high condition than in the low condition, $t(14) = 5.85$, $p < .001$, $ES_w = 1.33$, and $t(14) = 4.86$, $p < .001$, $ES_w = 1.13$, respectively. Thus, participants made contact with the holds longer, both with their hands and with their feet when they were anxious.

Overall, participants also moved slower from hold to hold in the high condition than in the low condition.[3] The average movement time from hold to hold in the high condition was 845 ms, which was significantly longer than the average movement time of 739 ms in the low condition, $t(10) = 2.89$, $p < .05$, $ES_w = 1.11$. Again, these slower movements occurred both with feet and hands. The average movement time for feet was significantly longer in the high condition than in the low condition, $t(10) = 2.27$, $p < .05$, $ES_w = 0.82$. The difference in average movement time for hands was not significant between high and low conditions, $t(10)$

[3] Movement time cannot be calculated if two feet or two hands touched the same hold at the same time. If this was the case switches remained activated when one of the hands or feet moved away, making it impossible to discriminate different movements. A total of 4 participants were not included in the movement time analyses as they touched a hold twice at the same time so often that not enough data were available to calculate average movement times.

= 1.80, $p < .10$, $ES_w = 0.76$.

To reiterate, in the high condition participants grasped the holds longer and they moved slower from hold to hold than in the low condition. Both longer contact times and slower movements contributed to the longer climbing times in the high-anxiety condition.

Table 3.3. *Total contact times[a], and average movement times[b] for the conditions in Experiment 2.*

	Condition			
	Low anxiety		*High anxiety*	
Variable	*M*	*SD*	*M*	*SD*
Total contact time	187	41.7	239	35.8
Total contact time feet	93	25.2	119	18.7
Total contact time hands	95	22.0	119	17.5
Average movement time	739	95.4	845	130.8
Average movement time feet	895	156.6	1023	223.2
Average movement time hands	543	74.01	599	122.4

Note: Movement patterns are not taken into account.

[a]In s.

[b]In ms.

Average movement times (for similar movements)

In principle, the above-mentioned differences could have been due to differences in movement pattern that were not taken into account. Different movement patterns may lead to different contact and movement times. Although averaged over all participants the number of performatory movements made did not significantly differ between the two conditions, there were large individual differences in climbing the low and high route. It might well be that the total contact times and the average movement times were the result of the use of different holds and different movement patterns rather than longer holding and slower movements. To correct movement times with respect to these possible movement pattern differences, we selected parts of traverses that were climbed in a similar way in both conditions.[4] This allowed us to calculate the average movement time for feet and the average movement time for hands. Eventually, 196 pairs of similar movements in the low and high condition (107 foot movement pairs and 89 hand movement pairs) could be analysed (about 26% of the total number of movements, cf. Table 3.2).

[4] We also executed analyses with 28 whole traverses that were climbed high and low using similar movement patterns. As the configuration of the handholds did not enable participants to climb the traverse without using one of the handholds with two hands at the same time (making it often impossible to distinguish different hand movements), we had to restrict these analyses to the movements of the feet. Results were similar to the results of the analyses that did not take into account movement pattern. That is, in the high condition participants stood longer on the holds, and they moved significantly slower from hold to hold than in the low condition. As a result climbing time was significantly longer in the high condition than in the low condition.

It appeared that participants' foot movements from hold to hold were significantly slower in the high condition (*M* = 964 ms, *SD* = 485.9) than were similar foot movements in the low condition (*M* = 847 ms, *SD* = 442.3), $t(106) = 2.55$, $p < .05$, $ES_w = 0.26$. In addition, it appeared that the average movement time for hands was significantly longer in the high condition (*M* = 596 ms, *SD* = 297.0) than in the low condition (*M* = 529 ms, *SD* = 194.6), $t(88) = 2.42$, $p < .05$, $ES_w = 0.34$. Thus, also when the movements were similar in both conditions, movement time of foot as well as hand movements appeared to be significantly longer in the high-anxiety condition than in the low-anxiety condition.

Discussion

The purpose of Experiment 2 was to provide more insight into how motor performance changes as a function of anxiety. We focused specifically on the temporal aspects of movements. The results showed that anxiety was successfully induced. Self-report scores indicated that participants felt more anxious in the high condition than in the low condition. Compared to Experiment 1 participants reported substantially higher anxiety scores, indicating that our change in the procedure between experiments (from climbing twice in each condition to climbing once in each condition) was successful. Again, heart rate appeared to be higher high on the wall than low on the wall, which might self-evidently also be a reflection of the longer climbing times.

As in Experiment 1, the higher self-report scores and the higher mean heart rate went hand in hand with longer climbing times and more exploratory movements. In addition, it appeared that participants also grasped holds longer, and on the whole they moved slower from hold to hold. These findings can largely explain the longer climbing times found under anxiety-provoking conditions and are in agreement with Masters' (1992) conscious processing hypothesis. In the *General Discussion* we will elaborate on this issue.

General Discussion

The main aim of the present study was to examine anxiety-related changes in participants' movement behaviour to gain insight into the mechanisms through which anxiety may affect performance in various settings such as sports (e.g., serving for match point in tennis), dance (e.g., auditioning for ballet school or performing), musical performance (e.g., making one's first appearance in a renowned orchestra), police work (e.g., shooting in the line of duty), work of fire fighters (e.g., rescuing people from the fire), and armed forces (e.g., flying a jet plane in war time). We set out from Masters' (1992) conscious processing hypothesis that under pressure one may resort to renewed conscious control of movements that would normally be executed automatically. In keeping with this hypothesis we expected that the changes in movement control would be reflected in movement behaviour as was also already found by Pijpers et al. (2003)—that is, longer climbing times in the high-anxiety than in the low-anxiety condition. In search for an explanation for these longer climbing times, we extended the investigation of the effects of anxiety on movement behaviour to (number of) limb movements and their temporal patterning.

Although the findings are in line with the hypotheses (see below), three alternative explanations need to be considered first. Next to differences in anxiety there are three other factors that may vary across conditions: the fact that participants practised low only, the difference in peripheral vision between conditions, and possible differences in task interpretation between conditions.

Practising low only

To guarantee a difference in anxiety and to prevent participants from habituating to the high-anxiety condition we could only have participants practise the low traverse. In principle, this could have given participants an advantage in this condition, leading to more efficient behaviour low on the wall and explaining the differences between conditions. However, we consider this option unlikely on the basis of two accounts. First, considering the principles of transfer of learning (e.g., Adams, 1987; Magill, 1998; Newell, 1981, 1985), there is no reason to believe that there was no positive transfer of practising the task low on the wall to performing the task high on the wall. The tasks in the low and high condition show large resemblances, making positive transfer very likely (see Magill, 1998).

Second, to find out whether the results could have followed from practising low only, we compared (for Experiment 2) climbing time of the last two traverses in the high condition with those of the first two traverses in the low condition. Thus, we compared two traverses in the high condition that were executed after the first two high traverses (which could be considered as high ‘practice’), with the first two low traverses that were executed after the low-practice trials. This was done irrespective of the order of conditions (high-low, or low-high). There was a significant effect of condition, with the high climbing times being longer than the low climbing times, $t(14) = 3.90$, $p < .001$, $ES_w = 0.79$, even though there was a general tendency that the fourth traverse was climbed fastest (see *Results* of Experiment 2). As a final test we compared, for those who climbed low first and then high, climbing time of the first two low traverses (preceded by the low practice trials only) with the last two high traverses (preceded by the low practice trials, the low condition—four traverses—and the first two high traverses). One would expect that on these last two traverses at least a similar advantage of experience with the task would have been present. Again, climbing times were significantly longer in the high than in the low condition, $t(7) = 2.03$, $p < .05$, $ES_w = 0.64$. Thus, even after some high practice the difference in movement execution between conditions remains, making it unlikely that practising the low traverse only was responsible for the more efficient performance in the low condition than in the high condition.

Difference in peripheral vision

There is also a difference in the peripheral field of view in the low and high conditions, which might be responsible for the differences found in movement behaviour. But it is important to realize that this is part and parcel of our anxiety manipulation. The evoked anxiety in the high condition may partly follow from the modified peripheral vision. It is unclear how the changed peripheral vision itself would change task execution, especially since participants moved very close to the wall. As it is unlikely that peripheral vision outside the traverse contributes to the control of the climbing movements, it is also unlikely that the change in peripheral vision itself would explain the changes in movement behaviour.

Task interpretation

Another option is that participants may have approached the two traverses, high and low, differently, perhaps leading to different strategies in climbing and consequently to differences in behaviour. To exclude this possibility, the 11 participants of whom a complete dataset was available (see also Footnote 3) were divided in two 'anxiety' groups on the basis of their anxiety thermometer scores when climbing the *high* traverse: a 'lower anxious' group (M = 5.0, SD = 1.53, n = 5) and a 'higher anxious' group (M = 7.7, SD = 0.86, n = 6), $t(9) = 3.58$, $p < .05$. If the high-low differences are attributable to anxiety, movement behaviour of the lower anxious group should be different from the movement behaviour of the higher anxious group when climbing high. If, however, high-low differences are due to strategic differences, no differences in movement behaviour are to be expected as all participants in this comparison received the same instruction and climbed in the same environment—that is, high on the wall. We did find significant differences between these two groups on most of the relevant variables: climbing time, traverse time, rest between traverses, number of performatory hand movements, total contact time, total contact time feet, and total contact time hand, ts > 1.90, ps < .05. It is difficult to interpret these differences as following from different task interpretations as the task and task environment were now identical for all participants in this comparison.

The factor that remains as explanation for the differences found in movement behaviour is anxiety. It appeared that the longer climbing time in the high condition could be explained for a small part by an increase in the number of explorative movements, an indication of the uncertain (hesitant) movement behaviour that also characterizes the early learner. In Experiment 2 we also found that in the high-anxiety condition participants not only grasped the holds longer, but they also made slower movements from hold to hold, again changes in movement behaviour that may also be found when there is more conscious processing, due to an inward focus of attention to the step-by-step control of skill execution. Thus, when participants were anxious their movement behaviour resembled the movement behaviour that can also be found in earlier stages of learning (see also, Baumeister, 1984; Beilock, Carr, et al., 2002; Beilock, Wierenga, & Carr, 2002; Liao & Masters, 2002; Hardy et al., 1996; Mullen & Hardy, 2000; Pijpers et al., 2003). This generally confirms Masters' (1992) conscious processing hypothesis. All in all, together with other findings in the recent literature (e.g., Beilock & Carr, 2001; Lewis & Linder, 1997; Mullen & Hardy, 2000) the (indirect) empirical support for the conscious processing hypothesis seems quite substantial.

The conscious processing hypothesis seems fit to explain the well-known and dreaded phenomenon of choking under pressure (Baumeister, 1984), especially when one is executing a concrete task—for example, in sports when one takes a decisive penalty shot in football or putt in golf under high situational demands. Performers who are about to execute that kind of tasks venture to reinvest in controlled processing: They are likely to think about what they are doing and what they have to do. Hence, despite individual striving, performance decreases. Thus, the conscious processing hypothesis seems to provide a plausible explanation for the relation between anxiety and performance especially when it concerns the execution of concrete tasks that are clearly 'defined from start to end', and that are self-paced, such as golf putting (Beilock & Carr, 2001; Beilock, Carr, et al., 2002; Hardy et al., 1996; Mullen & Hardy, 2000). Eysenck and Calvo's (1992) processing efficiency theory (see Footnote 1) seems to be more concerned with effects of anxiety on performance *throughout* an extended pattern of activities (e.g., an entire match or season) when performers often appear to maintain performance through additional effort.

Whether changes in movement behaviour actually result in a deterioration of performance may also (next to the task itself) depend on task instruction. It may be the case that using the same task but providing different instructions may lead to support for either the processing efficiency theory or the conscious processing hypothesis. For instance, when participants were forced to climb traverses in a fixed preset time of 20 s (Pijpers et al., 2003, Experiment 1; see Chapter 2) it was found that anxiety went hand in hand with a maintenance of performance as well as with more muscle tension and a higher blood lactate concentration as would be predicted by Eysenck and Calvo's (1992) processing efficiency theory. These results suggest that with additional efforts participants were able to climb the high traverse in the same time as they did the low traverse.

Thus, task domain (concrete task or continued activity), task instruction, and hence intention (does one strive for a personal best or just to complete the task without falling), seem to be important mediators of the anxiety-performance relationship. To account for the wide range of possibilities of the influence of anxiety on different aspects of performance in the fields of sports, dance, armed forces, and so on, it seems that the "best explanation currently available may be a combination of processing efficiency theory and the conscious processing hypothesis" (Edwards, Kingston, Hardy, & Gould, 2002, p. 14). Both process-oriented accounts of the anxiety-performance relationship may serve as a guide for future research to gain a better understanding of the multifaceted interaction between anxiety and performance.

As for the practical implications a crucial question is how choking under pressure can be prevented. When a skilled performer is in a high-achievement setting it seems important to prevent the inward focus of attention and the accompanying attempts towards conscious step-by-step control of movement execution. While this is easier said than done, this may be feasible by applying sport psychological training techniques (Le Scanff & Taugis, 2002; Morris, 1997; Wann, 1997). In the long run it may be better for teachers and instructors to organize the learning environment of perceptual-motor skills in such a way that eventually performance is less susceptible to the phenomenon of choking under pressure. This idea is supported by research into the paradigm of implicit versus explicit learning of perceptual-motor tasks (Hardy et al., 1996; Masters, 1992, 2000; Maxwell, Masters, & Eves, 2000; Wulf & Weigelt, 1997), which has demonstrated that preventing the development of explicit knowledge about task execution during the learning process may make performance less vulnerable to choking. This suggestion is corroborated by the studies into analogy learning in which only one explicit rule, rather than a large number of rules, guides the learning of the skill (Liao & Masters, 2001; Masters, 2000). Second, instructions that direct the learners' attention to the effects of their movements on the environment (external focus) and, thus, away from movement execution, appear to be more effective than instructions that direct performers' attention to their own movements and how to execute them (internal focus; Wulf, Höß, & Prinz, 1998; Wulf, McNevin, Fuchs, Ritter, & Toole, 2000; Wulf & Weigelt, 1997; for an overview, see Wulf & Prinz, 2001). Finally, next to the different ways of learning a skill (implicit vs. explicit, internal vs. external attention) the conditions in which learning took place appear to be crucial as well. Several studies show that when perceptual-motor skills are learned under conditions inducing self-awareness (Lewis & Linder, 1997), or self-consciousness (Beilock & Carr, 2001), choking is inoculated. Thus, getting used to the pressure may prevent choking, which provides an argument for simulating pressure-filled *learning* and *training* environments, which can easily be accomplished with the presence of a camera or (expert) spectators, placing (small) bets on performance, or practice contests, as long as the stakes and, hence, self-consciousness and pressure, are increased.

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Chapter 4

The role of anxiety in perceiving and realizing affordances

Abstract

Three experiments were conducted to examine the role of anxiety in perceiving and realizing affordances in wall climbing. Identical traverses were situated high and low on a climbing wall to manipulate anxiety. In Experiment 1 participants judged their maximal overhead reachability and performed maximal reaches on the climbing wall. Anxiety was found to reduce both perceived and actual maximal reaching height. In Experiment 2 participants climbed from right to left and back again on the high and low traverses, which now entailed an abundance of holds. Consistent with the reduction of perceived and actual maximal reaching height found in Experiment 1, anxiety led to the use of more holds. Finally, in Experiment 3 points of light were sequentially projected around the participants while they were climbing to measure attention. As participants detected less lights in the high-anxiety condition, it was concluded that anxiety narrowed attention. In general, the results underscored that the actor's emotional state plays an important role in perceiving and realizing affordances and that the perception of affordances changes as the accompanying action capabilities change.

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Introduction

When anxious, it is often difficult—quite literally—to keep things in perspective, as is illustrated by anecdotal evidence. In an attempt to conquer K2 (Karakorum Peak No. 2, 8616 metres high, Pakistan), mountaineer Ronald Naar was faced with a small wall of ice. Usually, he would not have had any difficulty overcoming such an obstacle, but on this particular occasion—according to his auto report—he suddenly froze with fear and the ice wall seemed to him more problematical to surmount than the most horrifying key passages he had seen and conquered in his long career as a climber (Naar, 1996). Apparently, anxiety prevented Naar from detecting the relevant information and finding the correct solution to the motor problem confronted. Thus, anxiety may affect perception and, hence, the selection of actions.

The anxiety-performance relationship has been studied extensively and is one of the most widely investigated and debated areas in sport psychology (e.g., Woodman & Hardy, 2001).[1] A number of models have been put forward to describe and explain the relationship between anxiety and performance, such as the inverted-U hypothesis (e.g., Yerkes & Dodson, 1908; Woodman & Hardy, 2001), the drive theory of Hull and Spence (Hull, 1943; Spence & Spence, 1966), Apter's reversal theory (Apter, 1982; Kerr, 1997), Hanin's individualized zone of optimal functioning (IZOF) hypothesis (e.g., Hanin, 2000), the multidimensional models (Martens et al., 1990), and the cusp catastrophe model (Hardy, 1990, 1996). It is beyond the scope of the current study to describe these models. Moreover, several excellent overviews of theories on anxiety and performance are available in the literature (e.g., Cox, 2002; Gould, Greenleaf, & Krane, 2002; Janelle, 2002; Jones, 1995; Landers & Boutcher, 1998; Raglin & Hanin, 2000; Weinberg, 1990; Woodman & Hardy, 2001).

Most important for now is that, despite the evolution of these models, the mechanisms underlying the relationship between anxiety and performance are still poorly understood (e.g., Janelle, 2002; Mullen, Hardy, & Tattersall, 2005), as theorizing in anxiety research remains troubled by the absence of consistent experimental findings regarding the effect of anxiety on human motor performance (Jones, 1995; Kleine, 1990). One of the reasons for this state of affairs is probably the prevalence of product-oriented approaches in pertinent research, which, by definition, ignore that the effect of anxiety on performance is mediated by a wide variety of processes (e.g., Collins, Jones, Fairweather, Doolan, & Priestley, 2001). To better understand this mediation, and thus to help disentangle the multifaceted relationship between anxiety and human motor performance, the present study adopts a more process-oriented approach. Ecological psychology offers a conceptual framework for pursuing the latter kind of approach in the domain of interest, and as such provides, at least in our view, an expedient

[1] Anxiety is conceived as a multidimensional construct having a cognitive component (i.e., worry, apprehension), and a physiological arousal component (i.e., the physiological response to anxiety-inducing situations) (Martens, Vealey, & Burton, 1990).

and promising theoretical framework for studying the influence of the actor's state variables such as anxiety, fatigue, and anger on perception and action, even though, admittedly, attempts in this direction have been few and far.

In ecological psychology (Gibson, 1979), perception is viewed as the active pick-up of information specifying 'affordances', that is, the behavioural possibilities offered by the environment (also called 'action possibilities' or 'behavioral potential' [Bhalla & Proffitt, 1999; Proffitt, Bhalla, Gossweiler, & Midget, 1995]). The theory of affordances provides a conceptual framework for understanding the interactions between 'actors' (humans and other animals) and their environment. It is founded on the premise that the environment is perceived in action-relevant terms, that is, in terms of what the actor can do with and in the environment. If the environment affords a particular action for a particular actor (human or animal), then that actor possesses certain properties that allow that particular action to take place in the environment. In ecological psychology, the latter properties are sometimes referred to as 'effectivities' (Shaw, Turvey, & Mace, 1982; Turvey, 1992; Turvey & Shaw, 1979). In that account, affordances and effectivities are seen as complementary dispositional properties, both of which are necessary conditions for the actor-environment system to exhibit an action (Turvey, 1992).[2]

If an actor is perceiving affordances while being engaged in a particular activity, he or she must be capable of perceiving the relation between environmental properties and the properties of his or her own action system. By implication, actions are 'body-scaled' (e.g., Warren, 1984, 1988). For example, to successfully reach for objects, people must scale the distance of the object in terms of their effective reach actions, which are constrained by geometric measures (e.g., arm length, leg length; see, e.g., Carello, Grosofsky, Reichel, Solomon, & Turvey, 1989; Mark, 1987; Mark et al., 1997; Warren, 1984, 1988). Initial research on affordances was focused on these 'invariable' intrinsic anthropometric body measures such as leg length (Warren, 1984), or arm length (Carello et al., 1989). Konczak, Meeuwsen, and Cress (1992) emphasized that action capabilities are not exclusively defined by anthropometrics, but that most perceptual-motor tasks are also subject to additional biomechanical constraints such as strength, limb mobility, and joint flexibility. They demonstrated that the perception of affordances (judgment of climbability of stairs) needs to

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[2] In ecological psychology there is an ongoing debate about the concepts of affordances and effectivities (e.g., Chemero, 2003; Heft, 2003; Michaels, 2003; Stoffregen, 2000, 2003). For instance, Stoffregen (2003) argued that affordances should be defined as emergent properties at the level of the animal-environment system rather than as properties of the environment that require complementary properties of the animal, that is, effectivities. In this respect Stoffregen's definition of affordances differs qualitatively from that of Turvey (1992). However, irrespective of one's position in this discussion, it is important to identify and understand how properties of the animal-environment system constitute opportunities for action including the role of the actor's emotional state in perceiving and realizing affordances.

be related to observers' action capabilities, or, in Turvey's (1992) terminology, effectivities (see also Cesari, Formenti, & Olivato, 2003; Choi & Mark, 2004; Oudejans, Michaels, Bakker, & Dolné, 1996; Oudejans, Michaels, van Dort, & Frissen, 1996; Pepping & Li, 2000).

So far the role of the actor's emotional state (i.e., anxiety or fatigue) in perceiving and realizing affordances has only been addressed in a few studies. Proffitt and Bhalla (Bhalla & Proffitt, 1999; Proffitt et al., 1995) conducted a series of experiments showing a relation between an actor's state and the perceived steepness of hills. They found that as hills are harder to traverse when participants are exhausted, wear a heavy backpack, or are older, they look steeper. It seems that the capacity to traverse a hill changes the perception of the steepness of the hill despite the fact that the actual steepness remains the same. Thus, there seems to be a functional adaptation of perception of action possibilities to the actual action capabilities.

Pijpers, Oudejans, and Bakker (in press; see also Chapter 5) confirmed such a relationship for overhead reachability, which they found to change as a function of exertion. On a climbing wall, participants repeatedly climbed series of trials resulting in increased levels of exertion. Before and during climbing participants judged their maximum reaching height, as well as perceived exertion. On a separate day, participants again climbed a number of trials while performing actual maximum reaches. Perceived maximal reaching height appeared to follow changes in action capabilities: When there were no changes in action capabilities—that is, no changes in actual maximal reaching height—no changes in perceived maximal reaching height occurred. Only when the actual maximal reaching height changed, this was reflected in perceptual changes.

As far as we know, there is only one previous study that investigated the effects of anxiety on the perception of affordances. Bootsma, Bakker, van Snippenberg, and Tdlohreg (1992) asked participants to judge whether balls that passed laterally at varying distances were reachable. They found that anxiety did not influence the average judgment of maximum reachable distance. However, Bootsma et al. did not examine whether anxiety had an effect on the actual maximum reaching distance. The selected affordance scaled with a physical characteristic (i.e., maximum reach, mainly determined by arm length), and was thus assumed not to be affected by the anxiety manipulation. However, as acknowledged by Bootsma et al., if an experimental manipulation directly affects the action capabilities of an observer, then a change in the perception of reachableness of approaching balls might be expected.

Thus, it seems that as long as participants' behavioural potential (i.e., actual action capabilities or effectivities) is not influenced by a state variable such as anxiety (or fatigue), one would expect that the perception of action possibilities is not influenced either. However, when a state variable does induce changes in a participant's behavioural potential, one would expect accompanying changes in the perception of the action possibility in question. The first goal of the present study was to examine the role of anxiety in perceiving and realizing affordances. By using a climbing wall we determined perceived and actual maximal overhead reaching height under different anxiety conditions, which were created by placing the same climbing routes high and low on the wall (cf. Pijpers, Oudejans, & Bakker, 2005; Pijpers, Oudejans, Holsheimer, & Bakker, 2003). Overhead reaching and adequately perceiving overhead reachability are important to the performance of daily actions (e.g., grasping an item from the highest shelf in the supermarket), as well as in sports in which, for instance, a ball has to be caught or hit. Adequately perceiving overhead reachability is also essential in the task investigated in the present study—sport climbing—where misperception may lead to falling. In Experiment 1, the effect of anxiety on perceived as well as actual maximal reaching height was investigated to determine whether changes in perceived maximal reaching height were accompanied by changes in actual maximal reaching height. In Experiment 2 we explored whether increased anxiety and the accompanying changes in perceived and actual maximal reaching height also affected participants' selection of action possibilities on the climbing wall. Finally, in Experiment 3 we investigated the impact of anxiety on attentional processes on the climbing wall.

Experiment 1

We expected that at higher levels of anxiety the actual maximal reaching height would decrease for two reasons. First, changing an individual's state (i.e., becoming more anxious) induces changes in movement execution such as higher muscle tension and jerkier, more rigid, and slower movements (e.g., Beuter & Duda, 1985; Collins et al., 2001; Mullen & Hardy, 2000; Pijpers et al., 2005; Weinberg, 1978). Second, reaching out as far as possible involves a chain of sub-movements such as stretching out the arm as far as possible, rotations in hips, back and shoulders, stretching the legs, and standing on tiptoe, implying that any effect of anxiety on these sub-movements, however small, will result in a culmination of errors along an entire biokinematic chain, which enhances the possibilities for establishing anxiety effects on an outcome measure such as actual maximal reaching height (cf. Parfitt, Jones, & Hardy, 1990; Weinberg, 1990). In view of the theoretical considerations offered in the preceding, we further expected that the predicted decreases in actual maximal reaching height would be accompanied by decreases in perceived maximal height.

Method

Participants

A total of 12 female participants, mean age 23.0 years (*SD* = 1.21), volunteered to participate in the experiment. The participants, for the greater part university students, had no experience in climbing and were naive with regard to the purpose of the experiment. They all provided written informed consent.

The Dutch version of the A-Trait scale of the State-Trait Anxiety Inventory (STAI)[3] was used as a standard check to measure trait anxiety (Spielberger, Gorsuch, & Lushene, 1970; van der Ploeg et al., 1979). The mean trait anxiety score for the participants was 30.8 (*SD* = 6.28), and was significantly lower than the mean score for Dutch female college students (*M* = 37.7, *SD* = 8.4) obtained by van der Ploeg et al. (1980) on a *t* test between a sample and a population mean (Thomas & Nelson, 1996), $t(11) = 3.83$, $p < .05$. The results indicated that the participants had no extraordinary tendency to respond to situations perceived as threatening with an elevation in state anxiety (e.g., Martens, 1982; Smith, Smoll, & Wiechman, 1998).

Experimental Set-up

Participants climbed on a vertical climbing wall (width: 3.5 m, height: 7.0 m; see Figure 4.1), which was set up in a large experimental room. The wall consisted of nine laminate panels with a grey grainy texture for friction. Holds could be bolted anywhere on the wall at relative distances of 0.24 m in horizontal direction, and 0.17 m in vertical direction. On the wall, two identical horizontal routes (so-called 'traverses', designed by a professional route designer) were mounted (see Figure 4.1). Each traverse consisted of six footholds and six handholds of varying size and shape, which were all suitable for novice climbers. The mean height of Holds 3 and 4 (see Figure 4.1) of the low traverse (*low* condition) and high traverse (*high* condition) were 0.30 m and 3.60 m, respectively. (Participants were standing on these holds when judging maximal reachability; see Procedure.)

[3] The STAI A-Trait scale is a self-report questionnaire that measures anxiety proneness—that is, the tendency to respond to situations perceived as thrilling with an elevation in state anxiety intensity. Scores range from a low of 20 to a high of 80 (van der Ploeg, Defares, & Spielberger, 1979, 1980).

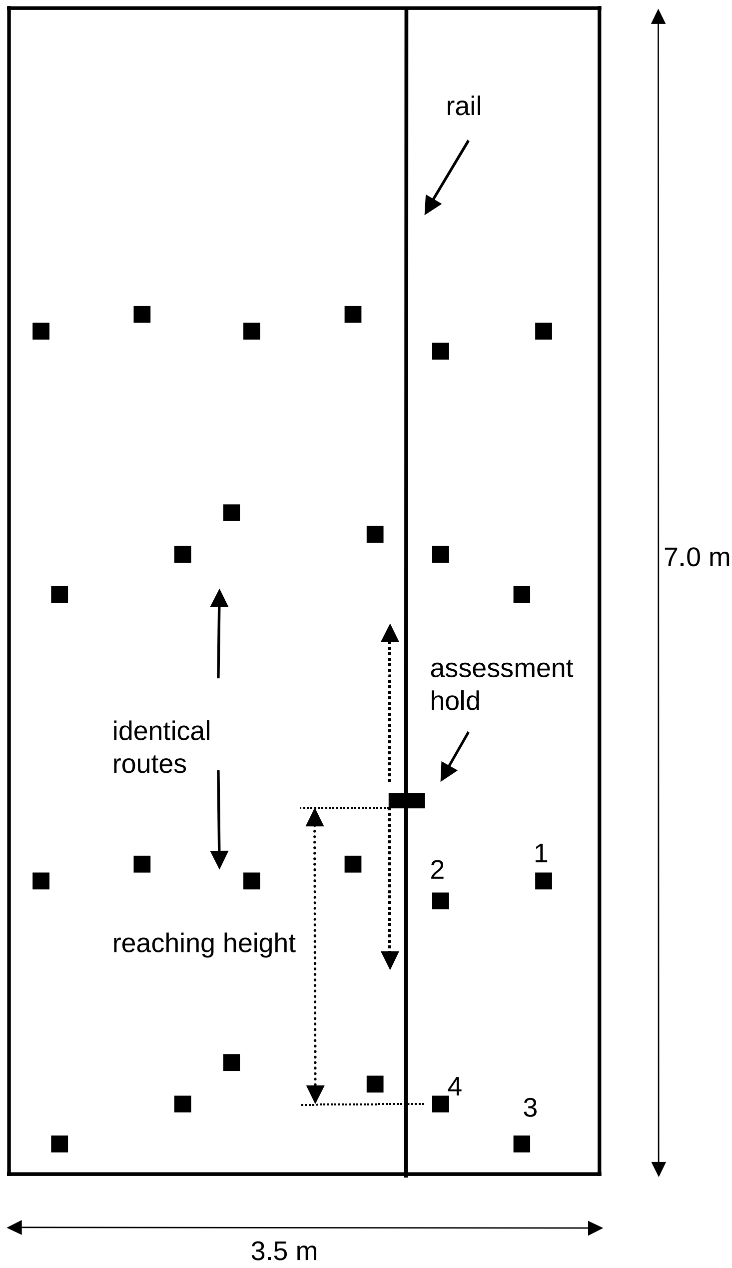

Figure 4.1. *Front view of the layout of the climbing wall used in Experiment 1. Black squares indicate the positions of the holds. The routes in the low and high condition are identical. The assessment hold (indicated by ▬) could be moved freely along the rail. Holds 1-4 indicate the position in which the perceptual judgements of maximum reaching height and actual maximum reaches were made (see also text).*

One hold, the 'assessment hold' (the black rectangle, see Figure 4.1), was movable in vertical direction. This hold was used to estimate the upper limit that participants perceived they were able to reach (the dependent variable *perceived maximum reaching height*), and that participants could actually reach (the dependent variable *actual maximal reaching height*).

The assessment hold could be moved freely along a rail, which was placed between the laminate panels of the wall and extended the entire height of the climbing wall (see Figure 4.1). The assessment hold was connected with ropes that could be used to pull the hold up or down. Reference points were removed by covering a part of the climbing wall (0.40 m on both sides of the rail) with black tape. (Post hoc interviews indicated that none of the participants made use of reference points when making their assessments.) A flexible tape measure was used to measure the distance between the assessment hold and Hold 4 (see Figure 4.1) after each assessment, in order to determine perceived and actual maximal reaching height. Hold 4 was chosen as it provided a 'natural' basis from which the investigated reaching action (perceived or actual) took place, especially since reaching was done with the left arm (see *Procedure*).

To enable participants to make assessments in the high condition a large stepladder was used. The stepladder had a small platform that allowed participants to rest after having climbed it and to start the high traverse in the same physical (i.e., non-fatigued) condition as in the low traverse.

The participants wore well-fitting climbing shoes (Enduro 954, La Sportiva). In both conditions participants wore a climbing harness (Singing Rock). We used the so-called 'top-roping' technique to ensure the safety of the participants. Top–roping involves 'paired' climbing (Skinner & McMullen, 1993)—that is, one end of the rope was tied onto the participant's harness, and the safety rope ran up around a solid iron bar at the top of the climbing wall, and back to the ground. This end of the safety rope ran through the belay device on the belayer's harness. (The belayer is the person who is managing the safety rope and preventing and protecting participants from falling down if they lose grip on the wall.) If properly applied, using the top-roping technique reduces the risk of a considerable fall to zero.

State anxiety was assessed by means of the 'anxiety thermometer' validated by Houtman and Bakker (1989). The anxiety thermometer is a 10-cm continuous scale on which participants were asked to rate their anxiety feelings at a particular moment in time, ranging from 0 (*not anxious at all*, the left end) to 10 (*extremely anxious*, the right end). Participants had to place a cross on the 10-cm scale to indicate how they felt at a particular moment. The distance between the left end and cross (in mm) was used as a measure of the reported anxiety. Consequently, the anxiety thermometer provided a quick method for measuring state-anxiety in contrast to the often-used Competitive State Anxiety Inventory-2 (Martens et al., 1990; for a critical discussion of the CSAI-2, see Jones & Uphill [2004], and Woodman & Hardy [2001]), which would be unsuitable for our purposes (see also Pijpers et al., 2003). The validity and reproducibility of the anxiety thermometer are fair with correlation coefficients ranging between .60 and .78. Based on these data, the anxiety thermometer is deemed an appropriate instrument for measuring anxiety in a threatening real-life situation (Houtman &

Bakker, 1989). For each measurement, a separate anxiety thermometer was used.

During the assessments of perceived maximal reaching height, we recorded heart rate values every 5 s using a Sporttester (Polar Electro-3000). Afterwards, mean heart rate was calculated per condition. All assessments were videotaped using an S-VHS camcorder (sampling rate 50 Hz), allowing us to check specific aspects of the experiment if such a need would arise.

Procedure

Participants were tested individually on a single day. Their total involvement in the experiment was approximately one hour. Participants were informed about the procedure of the experiment, and then asked to read and sign an informed consent statement. They completed the Dutch version of the STAI A-Trait scale (van der Ploeg et al., 1979) and filled out an anxiety thermometer in order to familiarize them with this measuring device.

Participants were then briefed in detail about what was meant by maximal reaching whereupon they had to base their estimates of maximal reaching height. For the purposes of this study, the maximal reaching height was defined according to the following reaching action (for the numbering of the holds low on the wall, see Figure 4.1): Participants placed their left foot on Hold 4, right foot on Hold 3, right hand on Hold 1, and left hand on Hold 2, and imagined that they would stretch upwards as far as possible (keeping both feet on the holds; standing on tiptoe was allowed) using the left hand to grasp the assessment hold in such a way that it would be possible to hang on to it and to use it for climbing. Participants were not allowed to actually execute the reaching action.

Each participant was fitted with climbing shoes and harness, as well as a Sporttester. Prior to making the assessment of the perceived maximal reaching height participants were given the opportunity to practice on the wall as brief hands-on experience with the task may yield perceptual information about climbing actions having a substantial impact on participants' estimations of maximal reaching height (Pijpers et al., in press).

Subsequently, participants were asked to take position on the wall. The assessment hold (see Figure 4.1) was either lowered from about 1.5 m above Hold 2 (descending assessment) or pulled up from about 1.5 m below Hold 2 (ascending assessment), during which the participants had to verbally indicate when the assessment hold would just be reachable in the prescribed manner. Participants could fine-tune their judgments by telling the experimenter to move the assessment hold either up or down until they were confident that the assessment hold was at the perceived maximal reaching height. Then, by means of the tape measure the distance was determined to the nearest millimetre; for accuracy reasons, we always read off the tape measure at eye level. The descending and ascending assessments were presented in alternating order. One trial consisted of one descending and one ascending assessment. Consistent with previous research on perceptual judgment tasks using the method of limits (e.g., Mark, 1987; Mark, Balliett, Craver, Douglas, & Fox, 1990; Pufall & Dunbar, 1992), the average of the three descending/ascending combinations (i.e., three trials) was used as measure of perceived maximal reaching height for a given condition. Participants received no feedback about the accuracy of their assessments.

Perceptual judgments were made in a similar way high and low on the wall (high and low conditions were counterbalanced). In each condition participants performed three descending and three ascending trials. Immediately after each condition, participants were asked to rate their feelings of anxiety by means of the anxiety thermometer. Participants were asked to recall how anxious they had felt during the assessments and to record this on the anxiety thermometer scale. This was used as anxiety score for the condition in question.[4]

Participants were allowed a recuperation period of about 10 minutes after each condition. After the two perceptual judgment conditions participants' actual maximal reaching height was determined: In both 'actual' conditions, participants stood on the footholds (right foot on Hold 3, left foot on Hold 4), grasped with their right hand Hold 1 (see Figure 4.1), and stretched out as high as possible with their left hand while the experimenter positioned the assessment hold in such a way that hanging onto it was just possible. The height of the assessment hold was measured. This procedure was repeated once; just as with the perceptual judgments, the mean of the (two) assessments was the participants' maximal reaching height for the condition in question.

One of the experimenters served as belayer. In the low condition, the belayer acted so as to insure that both conditions were similar for the climber. Participants were informed before starting the climb in the low condition (mean height of the footholds, 0.4 m) that, despite the belayer, if they slipped they should break their fall themselves, as the safety procedure would not be effective at that climbing height.

Statistical analysis

The effect of height (low-anxiety condition, high-anxiety condition) was tested using one-tailed paired *t* tests. Effect sizes (*ES*), indicating how many standard deviations the means under consideration differed, were calculated by taking the ratio of the difference between the two means and the mean within cell standard deviation of the means (Mullineaux, Bartlett, &

[4] In retrospect, it may have been better if we had also asked participants to rate their feelings of anxiety briefly after performing the maximal reaches. However, as perceptual assessments and actual reaches were executed within the brief time span of about 25 minutes we had (and still have) no reason to believe that participants' anxiety would have been different during the actual reaches in comparison to the perceptual assessments. Moreover, we found significant differences in anxiety between the high and low conditions on this climbing wall in all the climbing experiments that we performed (e.g., Pijpers et al., 2003, 2005). Even if participants had to climb high on the wall twice in the same experiment anxiety was still significantly higher than low on the wall during the second time high on the wall (Pijpers et al., 2005).

Bennett, 2001; Thomas & Nelson, 1996). An effect size of 0.2 or less, about 0.5, and 0.8 or more, represents small, moderate, and large differences, respectively (Cohen, 1988). When necessary, two-factor repeated measures analyses of variance (ANOVAs) were used. Maughly's test of sphericity was used to determine whether there were any violations to sphericity for the repeated measures. If violations occurred, they were corrected according to the Huynh-Feldt procedure before determining whether the differences of interest were significant (Kinnear & Gray, 2000). Eta squared (η^2) assessed the explained variance in the ANOVA models. Pair-wise comparisons using *t* tests were made using the Bonferroni correction procedure (ibid.) to identify specific mean differences when a significant main effect was found. The *p* values that are reported on the basis of this Bonferroni method are scaled to the .05 alpha level, so that, as usual, *p* values smaller than .05 indicate a significant effect.

Results

State anxiety and heart rate

To determine whether the anxiety manipulation was successful, we performed a paired *t* test on both the anxiety thermometer data and the heart rate data. Participants reported significantly higher anxiety scores in the high condition (M = 4.5, SD = 2.52) than in the low condition (M = 1.7, SD = 1.57), $t(11) = 3.96$, $p = .001$, $ES = 1.35$. In addition, the mean heart rate (beats per minute or bpm) was significantly higher in the high condition (M = 119.1 bpm, SD = 16.62) than in the low condition (M = 108.9 bpm, SD = 16.97), $t(11) = 2.87$, $p = .008$, $ES = 0.61$. Thus, according to both measures the manipulation of anxiety was successful—that is, in the high condition participants were more anxious than in the low condition, implying that the high and low condition indeed represented a high-anxiety and a low-anxiety condition, respectively.

Actual maximal reaching height

The average actual maximal reaching height was lower in the high condition than in the low condition (see Table 4.1). This difference was marginally significant, $t(11) = 1.77$, $p = .052$, $ES = 0.20$, indicating that higher levels of anxiety seemed to have affected participants' actual maximal reaching.

Perceived maximal reaching height

A 2 (height: low-anxiety condition, high-anxiety condition) × 3 (trial: Trial 1-3) repeated measures *ANOVA* on the perceived maximal reaching height data (see Table 4.1) revealed a significant main effect of height, $F(1, 11) = 8.73$, $p = .013$, $\eta^2 = 0.44$, $ES = 0.34$, indicating that the average perceived maximal reaching height was significantly lower in the high-anxiety condition than in the low-anxiety condition. The main effect of trial and the interaction between height and trial were not statistically significant (Fs < 1).

Table 4.1. *Actual maximal reaching height[a] and perceived maximal reaching height[a] for the conditions in Experiment 1.*

	Condition			
	Low anxiety		*High anxiety*	
Variable	*M*	*SD*	*M*	*SD*
Actual maximal reaching height	209.4	11.43	207.1	10.48
Perceived maximal reaching height	207.6	11.36	204.0	11.34
Trial 1	207.8	11.35	204.6	10.13
Trial 2	207.6	12.13	204.1	11.00
Trial 3	207.5	11.34	203.2	10.98

[a]In cm.

Discussion

Self-reported scores indicated that participants felt more anxious in the high condition (anxiety thermometer score: 4.5) than in the low condition (anxiety thermometer score: 1.7). A score of 4.5 on a 10-point scale might be taken to imply that the anxiety was relatively low. However, a score of 4.5 indicates that participants felt more anxious than students who are about to enter a written examination (Houtman & Bakker, 1989), about as anxious as novice teachers just before a lecture (Houtman, 1990), and less anxious than youth speed skaters prior to the start of a 1500 m race at a national championship (Bakker, Vanden Auweele, & Moormann, 1992). In addition to the subjective experience, heart rate appeared to be significantly higher high on the climbing wall than low on the climbing wall. Thus, despite the fact that we selected a low trait anxious sample of females, the results clearly indicated that the anxiety manipulation was successful.

The results showed that in the high-anxiety condition participants' actual maximal reaching height was lower than in the low-anxiety condition, although the difference just failed to reach the 5% significance level. The decrease in actual maximal reaching height was accompanied by a decrease in perceived maximal reaching height. This finding is consistent with the theoretical expectation that the perception of affordances only changes as the accompanying action capabilities change (Bootsma et al., 1992; Gibson, 1979). The decrease in actual maximal reaching height is also in keeping with anxiety-induced changes in movement execution, such as more muscle tension and jerkier and slower movements (Pijpers et al., 2003, 2005; Weinberg, 1978; Weinberg & Hunt, 1976).

Note that the absolute difference between the low-anxiety condition and the high-anxiety condition was (only) 2.3 cm for the actual maximal reaching height and 3.6 cm for the perceived maximal reaching height. However, in both cases the range over which changes are to be expected is small. As for actual maximal reaching height, the values are comparable to loss in stature due to spinal shrinkage. Values of spinal shrinkage due to circadian variations as well as spinal compression that are reported in the literature vary from a few mm up to over one cm or up to 1% (see van Dieën & Toussaint, 1993), implying a reduction of about 1.7-1.8 cm for 1.7 m tall persons, the mean height of our participants (SD = 0.04). In light of these numbers an average momentary reduction of actual maximal reaching height of 2.3 cm due to anxiety can be considered substantial. Regarding perceived maximal reaching height, as participants' height was on average 1.7 m, it is highly unlikely that participants judged their maximal reach lower than 1.7 m. The range over which the judgments were made was maximally 40 cm, and probably even less. As such, the observed difference of 3.6 cm may also be viewed as substantial.

The question remains whether the anxiety-induced changes in perceived and actual maximal reaching height also lead to changes in the realization of action possibilities. For example, if one perceives a particular hold on the climbing wall as just reachable in a neutral condition but as no longer reachable when anxious, does that also lead to the selection of a hold that is safely within reach if such a hold is available? In Experiment 2 we addressed this question by examining whether anxiety and accompanying changes in perceived and actual maximal reaching height also affected participants' selection of action possibilities on the climbing wall, and consequently movement behaviour.

Experiment 2

We asked participants to climb a horizontal traverse in two anxiety conditions, low (low-anxiety condition) and high (high-anxiety condition) on the climbing wall. To ensure that participants had the opportunity to select more holds than strictly necessary to climb the traverse an abundance of holds (30) was used in building the traverse (see Figure 4.2). Previous studies (Pijpers et al., 2003, 2005) had demonstrated that a traverse consisting of 11 holds sufficed to climb from left to right on the same climbing wall. As the same hold could be used multiple times in climbing a traverse, we operationalized the selection of action possibilities by counting the number of movements made to climb the traverse. In doing so, we distinguished between performatory movements and exploratory movements (Gibson, 1988). Performatory movements are meant to reach a certain goal, for instance, moving a hand or foot from one hold to the next in order to use it as support for further climbing actions. Exploratory movements are primarily information gathering movements, for example, when a climber wants to explore whether a hold is within reach. We predicted that the participants would make both more performatory and exploratory movements in executing the climbing task in the high-anxiety condition than in the low-anxiety condition.

Method

Participants

A total of 12 participants, 6 male and 6 female,[5] mean age 20.8 years (*SD* = 3.57) volunteered to participate in the experiment. None of them had participated in Experiment 1. The participants, all college students, had no experience in climbing and were naive to the purpose of the experiment. All provided informed consent.

The mean trait anxiety score for the male participants was 34.8 (*SD* = 4.26), and was not significantly different from the mean score for Dutch male college students (*M* = 36.1, *SD* = 8.4) obtained by van der Ploeg et al. (1980) on a *t* test between a sample and a population mean (Thomas & Nelson, 1996), $t(5) = 0.73$, *ns*. The mean trait anxiety score for the female participants was 34.0 (*SD* = 5.66), and was not significantly different from the mean score for Dutch female college students (*M* = 37.7, *SD* = 8.4; van der Ploeg et al., 1980), $t(5) = 1.60$, *ns*. The results indicated that the participants had no extraordinary predisposition to respond across many situations with high levels of state anxiety (e.g., Smith et al., 1998).

Experimental Set-up

Participants climbed on the same climbing wall as that used in Experiment 1. Again, two identical horizontal routes were mounted low and high on the wall, each consisting of 15 footholds and 15 handholds (see Figure 4.2). The mean height of the footholds of the low traverse was 0.36 m (low-anxiety condition) while that of the high traverse was 3.69 m (high-anxiety condition). To enable participants to start climbing in the high condition the stepladder was again used.

As in Experiment 1, participants wore well-fitting climbing shoes and a climbing harness connected to a climbing rope. The same security procedure as in Experiment 1 was used. All climbs were videotaped using an S-VHS camcorder (sampling rate of 50 Hz); participants' hand and foot movements were clearly visible. We used a stopwatch to determine climbing time (see *Dependent Variables* for a definition of this variable).

State and trait anxiety were measured in the same way as in Experiment 1. We decided not to use heart rate as a measure of state anxiety, because a higher heart rate in the high condition is also a reflection of physical strain. Increased climbing time in the high-anxiety condition is a consistent and robust finding in these kinds of studies (cf. Pijpers et al., 2003,

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[5] In both Experiments 2 and 3 mixed samples of males and females were tested. We checked whether there were significant differences between males and females on the state anxiety scores as well as the performance measures reported in Experiments 2-3. No significant effects involving gender were obtained.

2005).

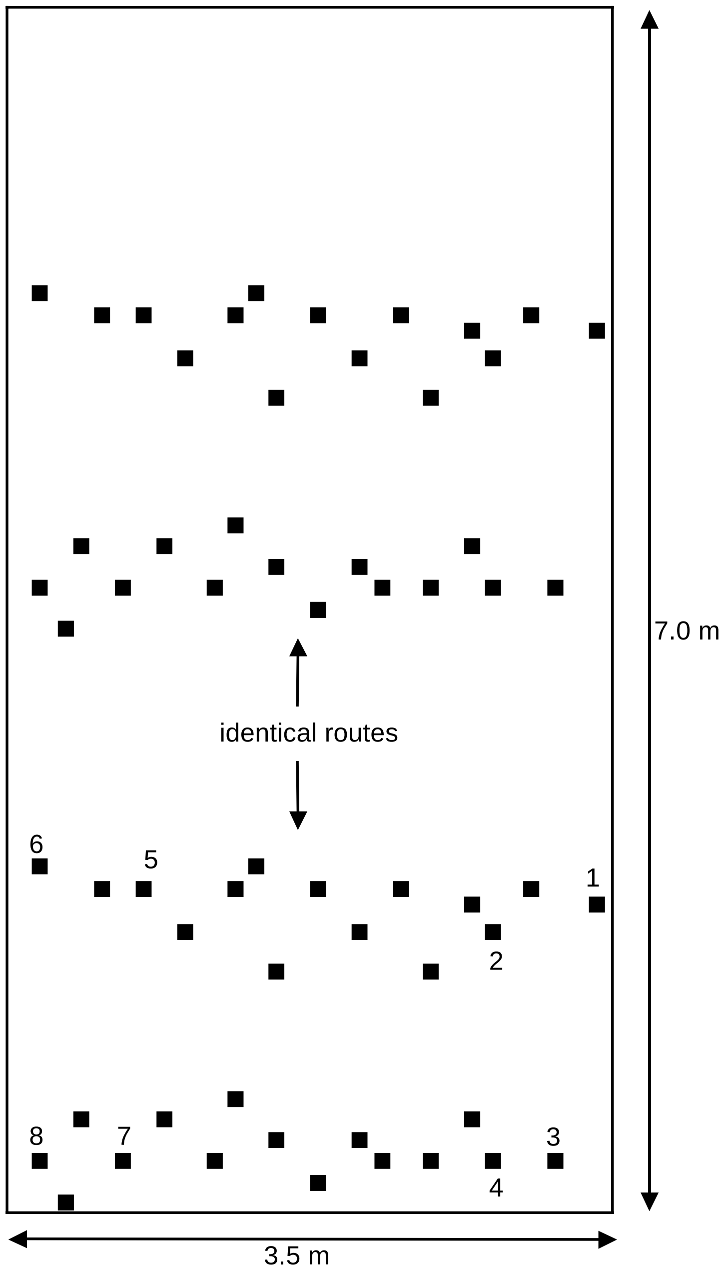

Figure 4.2. *Front view of the climbing wall used in Experiment 2. The routes in the low and high condition are identical. The positions of the holds are indicated by black squares. Holds 1-4 indicate the starting position. See text for explaining Holds 5-8.*

Task Execution

Participants were instructed to climb as fast and as safely as possible but it was stressed that the participant's first goal should be to complete the climbing task without falling. They were told that a fall would immediately end the experiment, and that the participant would be excluded from the experiment and subsequent analyses. During the experiment, none of the participants fell. No instructions were given as to how to climb faster, or which holds to use.

Procedure

Participants were tested individually on a single day. They were informed about the procedure of the experiment after which participants signed an informed consent statement. They completed the Dutch version of the STAI A-Trait scale (van der Ploeg et al., 1979).

After participants had put on their climbing shoes and harness, they practised climbing on the climbing wall. As the number of holds was more than sufficient to climb from the right side of the climbing wall to the left side and back again to the right side, all participants were able to successfully complete the practice task within a few minutes. As a consequence, the experimenters were confident that a participant's failure to complete the task in either condition was not due to lack of experience with the task.

After practice, participants were allowed 15 minutes to recuperate. Three minutes prior to running each condition, participants were positioned in front of the wall, either on the floor or the stepladder depending on the condition in question. Two minutes before the climb participants were asked to indicate how anxious they were at that moment by filling out an anxiety thermometer in order to familiarize them with the thermometer. Then, participants were connected to the safety rope. The camcorder was switched on and participants were instructed to begin when ready by assuming the starting position on the wall. They were considered to be in the starting position when they had placed their right hand on Hold 1, their left hand on Hold 2, their right foot on Hold 3, and their left foot on Hold 4 (see Figure 4.2). As soon as participants had assumed the starting position in the high condition, the stepladder was quickly removed. In the low condition, participants were instructed not to start climbing immediately, but to wait just as long as it would have taken to relocate the stepladder in the high condition (less than 10 s). In both conditions participants started climbing at a sign from one of the experimenters. Participants resumed the same position after they had climbed the traverse two times. Hence, participants climbed the traverse from the right to the left (ending with the right hand on Hold 5, left hand on Hold 6, right foot on Hold 7, and left foot on Hold 8; see Figure 4.2), and back to the right again. Immediately after the climb, the participants were asked to recall how anxious they had felt during the climb and to record this on the anxiety thermometer. This anxiety score was used as an anxiety score for that climb (and thus, for that condition).

After a recuperation period of at least half an hour the procedure was repeated, but now participants climbed in the other condition (high if they had started low; low if they had started high). The order of high and low conditions was reversed with every new participant (balanced over male and female participants).

Dependent variables

For each condition the following dependent variables were determined from the videotapes:

1. *Number of performatory movements,* defined as the number of movements during which a hold is released and contact is made with another hold, which is then used as support.

2. *Number of exploratory movements*, defined as the number of times a hold was touched without it being used as support.

Participants' movements were viewed by two independent raters for accurate determination of the dependent variables mentioned above. There was a 100% inter-observer agreement regarding performatory as well as exploratory movements.

3. *Climbing time* was also registered for each condition; it was defined as the sum of the time needed to climb the two traverses (from the right to the left, and back). As soon as participants released one of the holds in the starting position, time started. When participants had returned to the starting position, the time was stopped.

Statistical analysis

See Experiment 1.

Results

State anxiety

Participants reported significantly higher anxiety scores in the high condition (M = 4.8, SD = 1.81) than in the low condition (M = 2.2, SD = 1.98), $t(11) = 5.32$, $p = .0001$, ES = 1.33, indicating that the anxiety manipulation was again successful.

Behavioural variables

Table 4.2 presents an overview of the results concerning number of performatory movements (hand and foot movements), number of exploratory movements, and climbing time. The number of performatory movements was significantly higher in the high condition than in the low condition, $t(11) = 3.00$, $p = .006$, ES = 1.08. Investigating hand and foot movements separately, it appeared that significantly more performatory hand movements were made in the high condition than in the low condition, $t(11) = 3.90$, $p = .001$, ES = 1.21, as well as significantly more performatory foot movements, $t(11) = 2.11$, $p = .029$, ES = 0.76. Also the number of exploratory movements was significantly larger in the high condition than in the low condition, $t(11) = 2.76$, $p = .009$, ES = 1.14. Both the number of exploratory hand movements and the number of exploratory foot movements were higher in the high-anxiety condition than in the low-anxiety condition, $t(11) = 2.47$, $p = .016$, ES = 1.59, and $t(11) = 2.80$, $p = .009$, ES = 0.75, respectively.

It appeared that climbing time increased significantly from 45.8 s in the low condition to

78.8 s in the high condition, $t(11) = 5.62$, $p < .0001$, $ES = 1.73$. There were large individual differences in climbing time causing the large standard deviations. In the low condition climbing time ranged from 27 to 69 s, and in the high condition from 54 to 143 s.

Table 4.2. *Number of performatory movements, number of exploratory movements, and climbing time[a] for the conditions in Experiment 2.*

	Condition			
	Low anxiety		*High anxiety*	
Variable	*M*	*SD*	*M*	*SD*
Number of performatory movements	40.0	5.80	47.5	7.97
Hand movements	20.9	3.18	24.8	3.30
Foot movements	19.1	3.75	22.7	5.69
Number of exploratory movements	1.3	2.10	6.3	6.67
Hand movements	0.9	1.44	5.1	5.74
Foot movements	0.4	1.00	1.3	1.22
Climbing time	46	12.8	79	25.4

[a]In s.

Discussion

As expected, in the high-anxiety condition the abundance of alternatives to climb the traverse (provided by more holds) resulted in more movements, both performatory and exploratory. This indicates that a person's internal state plays a role in perceiving and realizing action possibilities: across anxiety conditions, participants selected different action possibilities from the plethora of action possibilities afforded by the environment.

In Experiment 1 it was found that changes in perceived and actual maximal reaching height occurred due to anxiety. These changes may partly account for the effects observed in Experiment 2. However, it is questionable whether the differences in perceived and actual reachability, which were in the order of magnitude of several centimetres, can fully explain why participants made so many more (performatory and exploratory) movements in the high-anxiety condition than in the low-anxiety condition. Note that using more holds implies shifts in grasping distance of (at least) 17 cm as the holds were 17 cm apart in vertical direction and 24 cm in horizontal direction, while changes in perceived and actual abilities were 'only' a few centimetres. It may be that on top of the changes in perceived and actual maximal reaching height, anxiety induced changes in participants' detection of relevant information for climbing, that is, in attention. Shifts in attention have been identified as one of the key mechanisms underlying changes (mostly decrements) in performance due to anxiety (Baddeley, 1972; Beilock & Carr, 2001; Janelle, Singer, & Williams, 1999; Landers, Wang, & Courtet, 1985; Liao & Masters, 2002; Mullen et al., 2005; Weltman & Egstrom, 1966; Weltman, Smith, & Egstrom, 1971). As attentional mechanisms might underlie the anxiety-induced changes in perception and realization of action possibilities that were found in

Experiments 1 and 2, a third experiment was conducted to examine the relationship between anxiety and attention in the climbing task.

Experiment 3

Two major accounts have been suggested in the literature to explain changes in attention due to anxiety (see Beilock & Carr, 2001; Janelle et al., 1999; Moran, Byrne, & McGlade, 2002). First, Easterbrook's (1959) cue-utilization theory states that as one experiences greater anxiety, the attentional field narrows (cf. Bacon, 1974; Janelle et al., 1999; Williams & Elliott, 1999). As a result, performance on central tasks will first be facilitated at the expense of performance on peripheral tasks, as peripheral (irrelevant) information will be blocked. At even higher anxiety levels, this funnelling effect may also prohibit attention to the information sources relevant for the central task, resulting in a decrement in performance on this central task. Second, performance decrements under stressful conditions can also be explained by the notion that anxious people are more easily distracted (Eysenck, 1992; Janelle et al., 1999). Within the distraction models it is proposed that some stimuli shift attention away from task-relevant information to task-irrelevant cues, thereby decreasing performance (see also Moran, 1996). It is assumed that increased pressure will cause individuals to focus on distracting stimuli either externally (e.g., crowd noise) or internally (e.g., worries) instead of focusing on task execution per se.

Although originating from an information-processing approach, attentional narrowing and distraction are not necessarily inconsistent with an ecological perspective. In ecological terms, attentional narrowing would imply missing less useful or non-specifying information[6] when anxiety increases. When anxiety increases further one might even start missing task-specific, specifying information as a result of which the performance of the main task would be hampered. Distraction would imply changes in the degree to which useful and less useful information draw the actor's attention. In terms of ecological psychology, there are changes in the 'attensity' of information surrounding the actor with 'attensity' defined as "a measure of the attraction that an area of information has for a perceiver." (Michaels & Carello, 1981, p. 71).

Based on the results of Experiments 1 and 2, one would expect that of these two mechanisms particularly attentional narrowing would play a role high on the climbing wall.

[6] A non-specifying information source may be related to a to-be-perceived property, but it is not specific to it as its value does not under all circumstances reliably predict the value of the to-be-perceived property (Beek, Jacobs, Daffertshofer, & Huys, 2003). Specifying information sources are specific to (to-be-perceived) properties of the environment. This means that detecting a certain information source that specifies a property of the environment allows the observer to make reliable judgments about this property (ibid.).

Therefore, in Experiment 3 we again asked novices to perform a climbing task in a low-anxiety and high-anxiety condition. In both conditions participants now simultaneously had to respond as quickly as possible to the appearance of a series of red lights projected on the climbing wall. If, as expected, attentional narrowing would occur participants would focus more on the primary climbing task and consequently detect fewer projected lights in the high-anxiety condition than in the low-anxiety condition, or they would at least respond slower to the detected lights if the number of detected lights remains the same. If, contrary to our expectations, (external) distraction would prevail (implying enhanced susceptibility to peripheral distracters, Williams & Elliott, 1999), one would expect that in the high-anxiety condition participants detect the same number or more projected lights with the same or a quicker response time than in the low-anxiety condition.

Method

Participants

A total of 17 participants, 5 male and 12 female, mean age 21.4 years (*SD* = 2.42) volunteered to participate in the experiment. The participants, all college students, had no experience in climbing and were naive to the purpose of the experiment. None of them had participated in Experiments 1 or 2. All provided informed consent.

The mean trait anxiety score for the male participants was 28.6 (*SD* = 4.93), and was significantly lower than the mean score for Dutch male college students (*M* = 36.1, *SD* = 8.4) obtained by van der Ploeg et al. (1980) on a *t* test between a sample and a population mean (Thomas & Nelson, 1996), $t(4) = 3.40$, $p < .05$. The mean trait anxiety score for the female participants was 33.8 (*SD* = 7.52), and was not significantly different from the mean score for Dutch female college students (*M* = 37.7, *SD* = 8.4, van der Ploeg et al., 1980), $t(11) = 1.80$, *ns*. The results indicated that the participants had no extraordinary predisposition to respond across many situations with high levels of state anxiety (e.g., Smith et al., 1998).

Task Execution

Participants were instructed to climb as fast and as safely as possible; however, their primary goal was to complete the climbing task without falling. They were told that a fall would immediately end the experiment, and that the participant would be excluded from the experiment and subsequent analyses. Participants had to climb the traverse four times—that is, starting at the left side of the wall the participants climbed to the right side (Traverse 1), then returned to the left side (Traverse 2), back again to the right side (Traverse 3), and back again to the left side of the wall (Traverse 4). It was also emphasized that participants should say out loud “Yes” as quickly as possible when they observed a red light that was projected on the climbing wall. Participants were informed that both tasks were equally important in terms of the overall performance score.

During the experiment, none of the participants fell. No instructions were given with respect to how to climb faster, or which holds to use.

Experimental Set-up

Participants climbed on the same climbing wall as that used in Experiments 1 and 2. Again, two identical horizontal routes were mounted low and high on the wall, each consisting of five footholds and six handholds (see Figure 4.3). The mean height of the footholds of the low traverse was 0.34 m (low-anxiety condition) while that of the high traverse was 3.68 m (high-anxiety condition). To enable participants to start climbing in the high condition the stepladder was again used (see Experiments 1 and 2).

For the peripheral light detection task, laser lights were projected on the climbing wall in the vicinity of the participants while they were climbing the traverse. For this purpose we developed a so-called 'laser pointer system' (LP-system) (see Figure 4.4). The LP-system consisted of a box with five laser pointers attached to it. There were four peripheral pointers and one central pointer. The LP-system was placed on a tripod, 1.31 m high, and at a distance of 7 m from the climbing wall. The laser pointers could be moved around a ball-and-socket joint to adjust the direction of the light beam and hence the projection of the lights on the climbing wall. With a handle attached to the LP-system the central laser pointer (labelled as 'ML', i.e., marker light; see Figure 4.4) could be moved up and down, and from the right to the left making it possible to direct it continuously on a marker on participant's back while he or she was climbing on the wall. Consequently, the four peripheral laser pointers projected their lights at (almost) the same distances from the participants irrespective from their climbing actions. In the high condition, the LP-system was directed upwards, and the angles of the lasers beams were adjusted in order to keep the positions of the lights relative to the participant identical as in the low condition.

The locations of the peripherally projected lights were (see Figure 4.4): right from the right shoulder (labelled 'RS'), left from the left shoulder (labelled 'LS'), right from the right hip (labelled 'RH'), and left from the left hip (labelled 'LH'). The LP-system was connected with a PC. By means of a specially developed software program (LabVIEW, National Instruments) it was possible to set the frequency, duration, and order of light activation of the laser pointers. During Traverses 1 and 3, the order of the lights projected on the climbing wall was set as follows: RS, RH, LH, and LS. During Traverses 2 and 4 the order was LS, RH, LH, and RS. Every 3.5 s a light was projected on the wall for 500 ms. The windows in the laboratory were blinded so that the light intensity was constant during the testing period. A stickpin-microphone (also connected to the computer) with a basic amplifier was used to pick up participants' "Yes" in order to calculate their response time (see also *Dependent Variables*). The software also provided a graphical representation of the moments laser pointers were switched on and off (and which laser pointer), and participants' verbal response to the appearance of the lights (by means of whimsical bursts in the output signal).

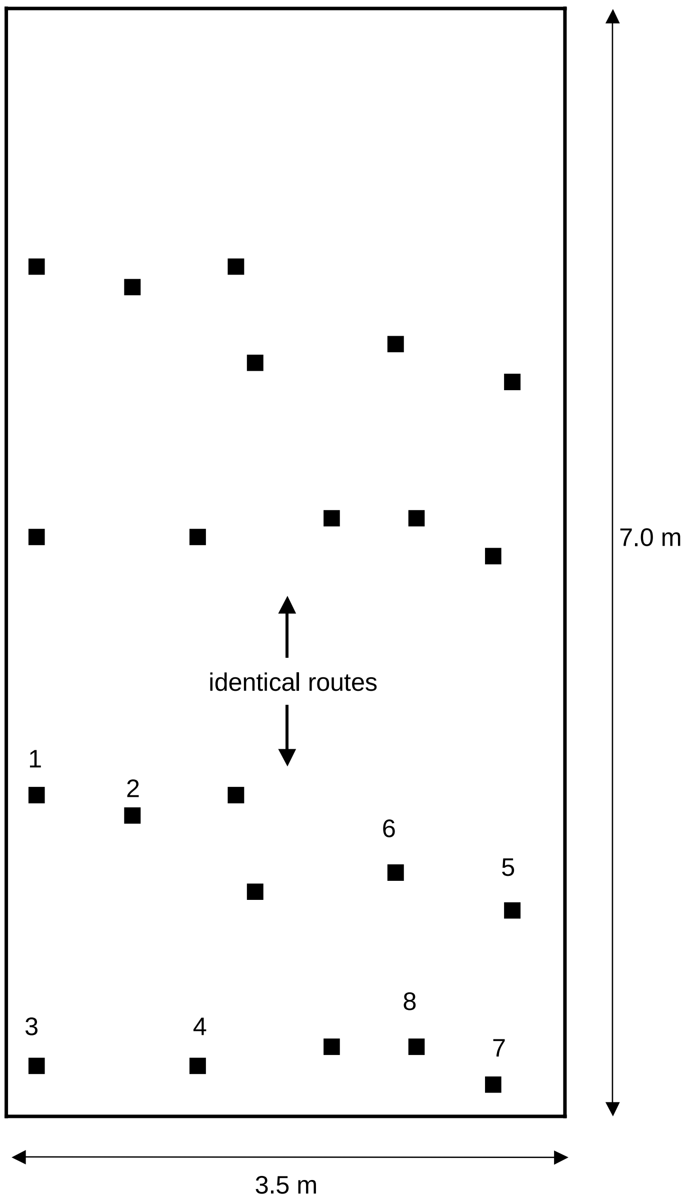

Figure 4.3. *Front view of the climbing wall used in Experiment 3. The routes in the low and high condition are identical. The positions of the holds are indicated by black squares. Holds 1-4 indicate the starting position. See text for explaining Holds 5-8.*

As in Experiments 1 and 2, participants wore well-fitting climbing shoes and an integral harness connected to a climbing rope. The same security procedure as in Experiments 1 and 2 was used. All climbs were videotaped using an S-VHS camcorder (sampling rate of 50 Hz).

The camcorder was placed next to the LP-system. State and trait anxiety were measured in the same way as in Experiment 2.

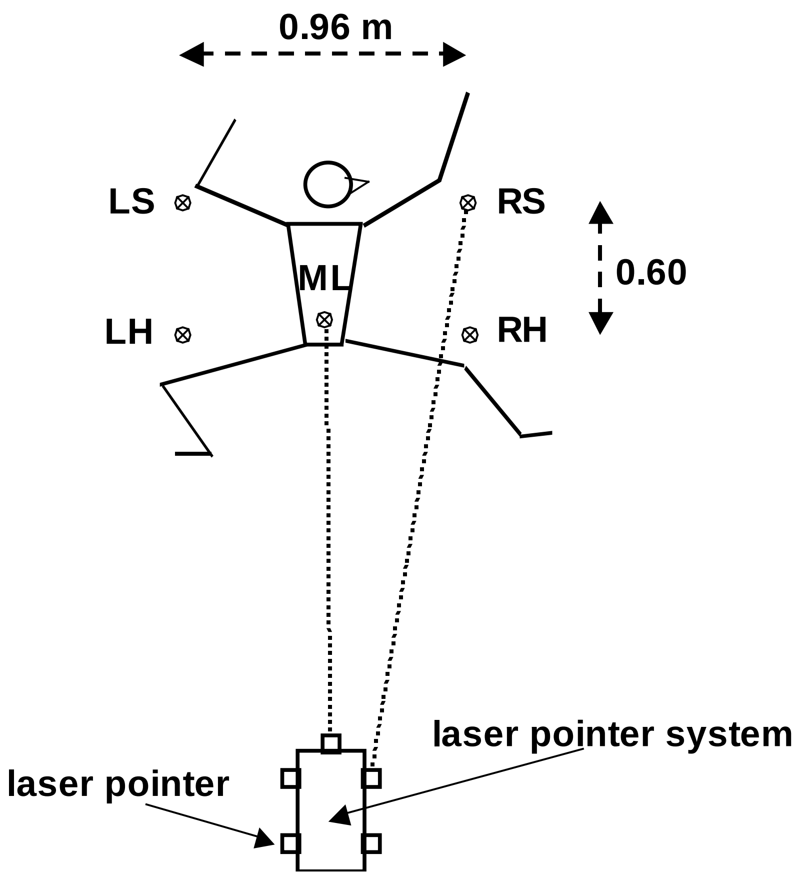

Figure 4.4. *Projection of the four peripheral lights on the climbing wall (LS = Left Shoulder, LH = Left Hip, RS = Right Shoulder, and RH = Right Hip). The central pointer (ML = Marker Light) was continuously directed at the marker on participant's back.*

Procedure

Participants were tested individually on a single day. The entire procedure was explained to each participant, and questions concerning the experiment were answered. Participants were then asked to read and sign an informed consent statement. After they had completed the Dutch version of the STAI A-Trait scale (van der Ploeg et al., 1979), the microphone was placed, and participants put on their climbing shoes and harness. They then practised the low traverse until they were able to climb the traverse two times back and forth. Practice periods lasted about 5 to 10 minutes. Then the lights were presented on the climbing wall while the participant was standing on it to (1) familiarize participants with the procedure and (2) to make sure that the lights fell within his or her peripheral visual field, which was the case for all participants. After this, participants were allowed to pause for at least 15 minutes.

Subsequently, the participants' task was explained in detail: specifically, they were told that the climbing task had to be carried out as fast and safely as possible, and that at the same time they had to say out loud “Yes” as quickly as possible each time they observed a red light. One minute before the climb participants were asked to indicate how anxious they were at that moment by completing the anxiety thermometer, again for the purpose of familiarization. They were then led to the climbing wall and connected to the rope. The camcorder was switched on, and participants were asked to take position on the wall: Participants placed their left hand on Hold 1, right hand on Hold 2, left foot on Hold 3, and right foot on Hold 4 (‘starting position’), (see Figure 4.3). As soon as participants had assumed the starting position in the high condition, the stepladder was quickly removed. In the low condition, participants were instructed to not start climbing immediately, but to wait just as long as it would have taken to reposition the stepladder in the high condition (less than 10 s). In both conditions participants started at a sign from one of the experimenters. They then climbed the traverse four times.

Immediately after each condition, participants were asked to recall how anxious they had felt *during* climbing and to record this on the anxiety thermometer scale. This was used as anxiety score for the condition in question. High and low conditions were counterbalanced.

Participants were allowed a recuperation period of about 30 minutes before starting the second condition. No feedback about their performance was given. The second condition was executed in a similar fashion as the first, but now participants climbed in the other condition (low if they had started high, high if they had started low).

Dependent variables

For each condition the following dependent variables were determined.

1. *Number of detected lights*, defined as the number of lights observed by the participants during climbing.

2. *Response time*, operationalized as the time between switching on a laser pointer and participant’s verbal response to it.

3. *Climbing time*, defined as the time needed to climb the traverse four times. Climbing time started as soon as participants had left the starting position and stopped as soon as participants had resumed the starting position after climbing the traverse four times. Climbing time was determined from videotape.

Statistical analyses

See Experiment 1.

Results

State anxiety

Participants had significantly higher anxiety scores in the high condition (M = 5.0, SD = 2.56) than in the low condition (M = 2.4, SD = 2.40), $t(16) = 4.23$, $p = .0003$, $ES = 1.04$. Thus, the manipulation of anxiety was again successful: participants were more anxious in the high condition than in the low condition.

Performance on the climbing task

As in our previous studies (Pijpers et al., 2003, 2005; see also Chapters 2 and 3), the climbing time in the high condition (M = 107.5 s, SD = 27.10) was significantly longer than in the low condition (M = 88.4 s, SD = 16.58), $t(16) = 4.66$, $p < .0001$, $ES = 0.88$. There were large individual differences in climbing time: In the low condition climbing time ranged from 69 to 137 s, and in the high condition from 73 to 175 s.

Performance on the light detection task

Due to differences in the average climbing times, the average number of lights that could be detected was 26.9 (SD = 6.78) in the high condition and 22.1 (SD = 4.15) in the low condition. Nevertheless, participants detected, on average, significantly fewer lights in the high condition (M = 3.7, SD = 3.10) than in the low condition (M = 6.5, SD = 3.47), $t(16) = 3.51$, $p = .001$, $ES = 0.85$. To diminish the confounding effect of climbing speed, we first determined which lights could have been detected by each participant. As the fastest participant needed 69 s to execute the task—that is, about 17 s per traverse—he or she could maximally have detected four lights per traverse. Therefore, we determined for each participant which lights were detected of the first four lights that were presented in Traverse 1, Traverse 2, Traverse 3, and Traverse 4. Each participant, including the fastest, could, in principle, have detected these first four lights per traverse, thus, 16 in total. Also according to this analysis, participants detected significantly fewer lights in the high-anxiety condition (M = 2.2, SD = 1.64) than in the low-anxiety condition (M = 4.6, SD = 1.91), $t(16) = 4.86$, $p < .0001$, $ES = 1.35$.

The 16 lights that could have been detected by all participants can be classified in lights that were presented in the direction of locomotion (the so-called ‘ahead’ detections), and lights that were presented in opposite direction (the so-called ‘detections). A 2 (Height: low condition, high condition) × 2 (Direction of locomotion: ahead, behind) repeated measures *ANOVA* on the detection data revealed a significant main effect of height, $F(1, 16) = 23.57$, $p < .001$, $ES = 1.33$, $\eta^2 = .60$, and a significant main effect of direction of locomotion, $F(1, 16) = 41.43$, $p < .001$, $ES = 1.43$, $\eta^2 = .72$, indicating that, on average, significantly more ‘ahead’ lights were detected (M = 2.6, SD = 1.59) than ‘behind’ lights (M = 0.8, SD = 1.05). The interaction between height and direction of locomotion was not significant, $F(1, 16) = 1.66$, $p = .22$.

The averaged response time was not significantly different between the high condition (M = 742 ms, SD = 217.5) and the low condition (M = 774 ms, SD = 242.7), $t < 1$.

Discussion

Findings generally confirmed the notion of attentional narrowing (Bacon, 1974; Easterbrook, 1959; see also Murray & Janelle, 2003) in that participants detected fewer lights in the high-anxiety condition than in the low-anxiety condition. Apparently, in the high-anxiety condition attention was more narrowly focused on information relevant for climbing, while information that was less relevant for climbing at that moment (projected lights) was overlooked.

It should be noted that under anxiety the reduction in the number of lights detected occurred despite the fact that in the low-anxiety condition, the number of lights detected was already low (about 25%). In the analyses presented in the preceding that were based on 16 lights (eight ‘ahead’ and eight ‘behind’ lights), 43% of the ‘ahead’ and 15% of the ‘behind’ lights were detected in the low-anxiety condition. This indicates that ‘merely’ climbing on the climbing wall is already attention consuming. In the high-anxiety condition only 23% of the ‘ahead’ lights and 4% of the ‘behind’ lights were detected, showing that almost all of the lights projected ‘behind’ the climbers were missed while only a quarter of the lights projected in front of the climbers were detected.

In short, the results point in the direction of attentional narrowing as more lights went undetected in the high-anxiety condition. However, as Janelle et al. (1999) remarked, the mechanisms of attentional narrowing and distraction could be operative simultaneously. Instead of focusing on task execution per se (climbing and detecting lights), participants may have been focusing on internally distracting stimuli such as worries and negative thoughts (also) leading to the detection of fewer lights. Visual search data may shed more light on the precise changes that occur under anxiety in visually attending to specific locations on the climbing wall (cf. Murray & Janelle, 2003; Williams & Elliott, 1999).

General Discussion

Gibson (1979) suggested that the environment is perceived in actor-relevant terms, that is, in terms of what an actor can do with and in the environment. In keeping with this notion, research has shown that changes in one’s potential to act influences the perception of action possibilities (e.g., Bhalla & Proffitt, 1999; Proffitt et al., 1999; Pijpers et al., in press). Based on that idea, we assumed that changes in the actor’s emotional state that lead to changes in his or her action capabilities will also lead to changes in the perception of those action possibilities. Perception-action experiments on a climbing wall allowed us to investigate the influence of the actor's emotional state—anxiety—on perceiving and realizing affordances.

Experiment 1 demonstrated that anxiety reduced both perceived and actual maximal reaching height. Subsequently, in Experiment 2 and in line with the results of Experiment 1, anxiety was found to affect the realization of action possibilities, leading to the use of more holds on the same traverse. Experiment 3 particularly provided support for attentional narrowing as an additional underlying mechanism (on top of the reduction of perceived and actual maximal reaching height) of the anxiety-induced changes in realizing affordances as found in Experiment 2. Note that grasping holds that are easily within reach rather than at the maximum of one's reachability is consistent with attentional narrowing. If attention narrows, one is bound to grasp those holds that are closer by and still within ones field of attention. Of course, these results do not discard the possibility that in Experiment 2 the use of more holds reflect a more conservative and safer climbing strategy independent of attentional narrowing.

The findings of Experiments 1 and 3 indicate that anxiety affects the detection of information about the action possibilities in the environment, while the findings of Experiment 2 (and Experiment 1) suggested that anxiety constrains the realization of action possibilities. In our view, these findings suggest how, from an ecological point of view, the perception and realization of affordances might be understood in situations in which emotional processes are in play.

As an entry point to discussing the theoretical implications, it is useful to first turn to the results of Jiang and colleagues (Jiang & Mark, 1994; Jiang, Mark, Anderson, & Domm, 1993) on the perception of gap crossability. They found that when individuals had to judge whether they could step over a gap, their estimates of crossable gap width decreased as gap depth increased. This finding seems to refer to a process similar to that addressed in the present study in that increased gap depth led to increased anxiety, which in turn affected the perception of gap crossing capability. However, Jiang and colleagues disputed that emotional processes were causing the more conservative assessments. They attempted to substantiate this claim by showing that estimates of gap crossing capability critically depended on where observers directed their gaze: when looking down into the gap, participants tended to underestimate their capabilities more than when they looked toward the horizon. This explanation, however, does not preclude the possibility that gaze direction and emotional processes co-varied (cf. Janelle et al., 1999; Murray & Janelle, 2003; Williams & Elliott, 1999; Williams, Vickers, & Rodrigues, 2002), that is, when participants looked down into the gap they may have felt some fear of the depth resulting from the increased risk to their safety. When they looked at the horizon participants may have felt no or less fear. Hence, anxiety might have played a role in the observed changes in the perception of gap crossability.

In line with previous findings (e.g., Bhalla & Proffitt, 1999; Proffitt et al. (1995), we once more found support for the intricate relation between the perception and the realization of action possibilities. An observer who is in a threatening environment will pick up information about that environment as well as information about his or her own (emotional) state. The latter will deviate from ordinary feelings, sensations et cetera, and the observer will behave accordingly. As such, the anxiety-induced bodily and physiological reactions are part and parcel of the properties of the animal-environment system in which affordances are perceived and realized. Many studies have reported all kinds of bodily changes under threatening conditions (e.g., Brooke & Long, 1987; Frijda, 1986; Weinberg & Hunt, 1976). Given the mutuality of observer and environment, it follows that changes in action capabilities will be detected, which will affect the individual's perception of affordances. Using a similar set up as that used in the present study, Pijpers et al. (2003) demonstrated considerable and significant increases in blood lactate concentration and muscle fatigue under anxiety. Evidently, the environment affected the neuromuscular system and participants accounted for these effects when asked to judge their maximal reaching height in that environment. Hence, anxiety-induced changes in action capabilities closely corresponded to changes in the perception and realization of affordances.

In conclusion, an actor's emotional state affects the perception and realization of affordances in a manner that is consistent with the changes that accompany this emotional state, such as changes in attention and actual action capabilities. Rather than portraying this emotional state as a spooky and subjective variable this once more emphasizes the intricate relations between actor and environment and perception and action.

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Chapter 5

Changes in the perception of action possibilities while climbing to fatigue on a climbing wall

Abstract

In two experiments we investigated changes in the perception of action possibilities as a function of exertion. In Experiment 1, participants repeatedly climbed on a climbing wall in series of trials that progressively increased in number up to 10 trials, resulting in increased levels of exertion. Before and during climbing participants judged their maximum reaching height, as well as perceived exertion. On a separate day, participants climbed another 10 trials while performing actual maximum reaches. Higher levels of perceived exertion were associated with decreases in perceived maximum reach while the actual reaches did not decrease. However, the perceptual changes were found early during task execution when participants were not yet fatigued. When exertion set in neither perceived nor actual maximum reaching appeared to be affected. In Experiment 2 we included exhaustion trials. The findings replicated the early changes in perception observed in Experiment 1, which may be accounted for by hands-on experience with the task. Furthermore, while climbing to exhaustion, perceptual judgements largely changed in keeping with changes in the actual maximum reach. Thus, there appeared to be a functional relationship between participants' actual action capabilities, rather than their state of physical fatigue per se, and perceived action possibilities.

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Introduction

In many sport settings there is an abundance of external and internal cues to yield relevant or irrelevant information that can be used to guide one's actions. Several factors mediating the selection of information, such as task experience (e.g., Abernethy, 2001), and competitive anxiety (e.g., Moran, Byrne, & McGlade, 2002; Williams, Davids, & Williams, 1999), have been studied extensively over the last few decades. However, the role of exertion in addressing the mechanisms by which (sport) performers pick up relevant information (Proffitt, Creem, & Zosh, 2001) has rarely been addressed. This is surprising as many competitive sports have a clear physical component often producing physical fatigue. Sports events are often decided in the dying minutes of the game when players are tired.

The study reported here examined the influence of the level of exertion on a perceptual judgement task, namely, perceiving overhead reachability. We have chosen this task for two reasons. First, in a number of sports, the proficiency of adequately perceiving overhead reachability is essential to performance, for instance, when a ball has to be caught (e.g., baseball or basketball), hit (e.g., serving or blocking in volleyball), or punched above the head (e.g., by a soccer keeper), or when holds have to be grasped in sport climbing. Second, the actual maximum reaching height can be easily measured so that participants' perception of their action possibilities can be related to their actual capabilities.

Although scarce, some empirical evidence exists for the view that perceptual judgements of action possibilities are influenced by fatigue. Proffitt and Bhalla (Bhalla & Proffitt, 1999; Proffitt, Bhalla, Gossweiler, & Midgett, 1995) conducted a series of experiments in which they showed that perceived steepness of hills is, in part, dependent on participants' state of physical fatigue. When participants were exhausted they judged hills to be steeper than when they were not fatigued. The authors also demonstrated that the judgement of the inclination of the hills was inversely related to participants' fitness level, and that elderly people were more prone to overestimate the steepness of hills than their younger counterparts. Moreover, participants who wore a heavy backpack verbally judged hills to be steeper than participants without a backpack. Thus, it seems that the capacity to traverse a hill changes the perception of the steepness of that hill even though its actual steepness remains the same. In other words, as hills are harder to traverse when participants are exhausted, wear a heavy backpack, or are older, they are perceived as steeper. In addition, since for biomechanical reasons hills are more difficult to descend than to ascend, hills look steeper when viewed from the top than from the bottom (Proffitt et al., 1995). Thus, there seems to be a functional adaptation of perception of action possibilities to the actual action capabilities.

Bhalla and Proffitt (1999) and Proffitt et al. (1995, Experiment 5) studied the perception of action capabilities in a binary fashion—participants were exhausted or not, wore a heavy backpack or not, were physically fit or not, or were around 20 or above 60 years of age.

Hence, their results remained mute with regard to possible intermediate changes in perception and action. Insight into these intermediate changes might provide an answer to the question whether the adaptation of perception of action possibilities is a function of physical state per se or of changes in actual action capabilities also referred to as 'behavioral potential' by Proffitt and Bhalla (Bhalla & Proffitt, 1999; Proffitt et al., 1995). A brief discussion of Gibson's (1979) theory of direct perception, also considered by Proffitt et al. (1995) as a suitable candidate to account for their findings on geographical slant perception, might underscore the relevance of this question. This theory also provides handles to distinguish the concept of physical state and that of behavioural potential or actual action capabilities.

In Gibson's (1979) theory of direct perception (see also Michaels & Beek, 1995), affordances are defined as the behavioural possibilities of an environmental layout taken with reference to a particular animal. "An affordance for a particular animal is a property of the environment that affords relevant behavior to the animal" (Jacobs, 2001, pp. 194-195). A ball affords—for example, throwing, hitting, catching, avoiding, or being hit in the head. The complement of an affordance as a property of the environment taken with reference to an animal is the property (or properties) of the animal with which that affordance can be realized. For instance, a certain arm length co-determines whether a cup on a table is reachable, and the size of the hand largely determines whether an object is graspable. Such properties, sometimes called 'effectivities' within the ecological approach (e.g., Shaw, Turvey, & Mace, 1982; Turvey, 1992), thus refer to the observer's action capabilities or behavioural potential (Bhalla & Proffitt, 1999; Proffitt et al., 1995).

According to Gibson (1979), a particular affordance exists irrespective of the state or need of that person. In other words, a change in the need or state of the observer does not alter the affordance (Gibson, 1979, pp. 138-139). Bootsma, Bakker, van Snippenberg, and Tdlohreg (1992) presented support for this hypothesis in an experiment in which participants were asked to judge whether balls that passed laterally at a distance varying around arm length were reachable under two conditions: a control condition and an anxiety condition. Bootsma et al. found that anxiety did not influence the average judgement of maximum reachable distance.

Bootsma et al. (1992) did not examine whether anxiety had an effect on the actual maximum reaching distance. The affordance of interest in their experiment was selected because it scaled with a physical characteristic (i.e., maximum reach, mainly determined by arm length), and was thus assumed not to be affected by the anxiety manipulation. However, as was also acknowledged by Bootsma et al., if an experimental manipulation directly affects the action capabilities of an observer (i.e., seriously fatiguing the arm muscles before making the judgements), then a change in the perception of reachableness of approaching balls might be expected.

Thus, it seems that as long as participants' behavioural potential (i.e., actual action capabilities or effectivities)[1] is not influenced by a state variable such as anxiety (or fatigue), one would expect that the perception of action possibilities is not influenced either. However, when a state variable does induce changes in participants' behavioural potential, one would expect accompanying changes in the perception of the action possibility in question.

The present study set out from the idea that there is a functional relationship between the perception of action possibilities and actual action capabilities, rather than just the observer's state of physical fatigue, defined as a state that results from changes in skeletal muscles, the depletion of the energy stores, and accumulation of lactic acid, which reduce people's performance capacity until they drop, or they can no longer put forth the required effort (e.g., Holding, 1983; Ulmer, 1989). Using a climbing task during which judgements of overhead reachability were made, we examined whether and how perceptual judgements change as a function of exertion and action capabilities, thereby extending the work of Proffitt and Bhalla (Bhalla & Proffitt, 1999; Proffitt et al., 1995), who studied just the two extreme levels of exertion, namely, rested and exhausted.

In Experiment 1 the level of exertion was systematically varied from rested to very fatigued. In Experiment 2 we also included exhaustion trials.

Experiment 1

In Experiment 1 participants executed a climbing task with progressively increasing levels of exertion. This was achieved by varying the number of times participants had to climb a route from right to left and back on an artificial climbing wall. At specific moments during climbing participants rated their perceived exertion using Borg's (1970) Ratings of Perceived Exertion-scale ('RPE scale'). Borg's RPE scale is widely used to measure perceived exertion, exercise intensity, or fatigue (Chen, Fan, & Moe, 2002).[2] At those moments participants also

[1] An in-depth discussion of the complementary concepts of affordances and effectivities can be found in a collection of papers that appeared in *Ecological Psychology* (Chemero, 2003; Heft, 2003; Jones, 2003; Michaels, 2003; Stoffregen, 2003). Although the importance of the affordance concept is fully recognised, much debate remains with regard to its precise definition and the role of effectivities in the theory of affordances (cf. Stoffregen, 2003; Turvey, 1992). To circumvent this discussion, we have chosen to use the terms 'action capabilities' and 'action possibilities' in the remainder of this chapter. We will use the term 'actual action capabilities' (cf. Michaels, 2003) to contrast it with 'perceived action possibilities'.

[2] Noble and Robertson (1996) argued that the term 'exertion' has often been criticized as inappropriate or too specific to endurance-type activities, and that some have suggested using other terms such as 'perceived fatigue', 'perceived effort', or 'perceived force'. They concluded, "Despite such suggestions, perceived exertion has become the term generally accepted for use with all types of human movement." (p. 4). Therefore, we also use the term 'perceived exertion' throughout this chapter.

judged how far they could reach overhead. At the end of the climbing tasks, blood lactate concentrations were measured to obtain a confirmation of the level of exertion. To be able to relate participants' perception of action possibilities to their actual action capabilities, we also determined participants' actual maximum reaching height at different levels of exertion. This was done on a separate day (see under *Method*).

We expected that the RPE scores, as well as blood lactate concentrations, would increase as the number of trials participants had climbed increased. Furthermore, as maximum overhead reaching involves stretching the whole body including the reaching arm, back, shoulders, the legs, and standing on tiptoe, we expected that at higher levels of exertion actual maximum reaching height would decrease. Finally, we expected that judgements of maximum reaching height would only decrease when the actual action capabilities are also affected, irrespective of the progressive increases in exertion.

Method

Participants

A total of 16 female participants (aged 19 to 31 years), mainly college students, volunteered to participate in the experiment. They had little or no experience in sport or rock climbing, and were naive to the purpose of the experiment. All participants signed a written informed consent, and were paid a small fee for their participation. The study's protocol was formally approved by the Local Ethics Committee of the Faculty of Human Movement Sciences before the experiment was conducted.

Design

The experiment was spread over four days. On *Day 1*, the participants became familiar with the experiment by practising the climbing task, which consisted of climbing a horizontal route on a climbing wall (see Figure 5.1) from the right side of the wall to the left and back to the right again, defining a single trial. On *Day 2*, participants performed two series of trials. First they climbed one of a series of 4, 6, 8, or 10 trials. After a recuperation time of at least one hour, participants climbed another series of 4, 6, 8, or 10 trials, excluding the one they had already climbed. On *Day 3*, participants climbed the remaining two series of trials. Hence, ultimately the participants performed all four series of trials in order to induce a 'continuum' of exertion. Participants were never informed about which series of trials they were climbing to prevent that they would adjust their climbing speed to that particular series, which would render the exertion manipulation ineffective. With each new participant a new order of series was selected randomly (without replacement) from the 24 possible orders of the series. Before climbing, and after every second trial we measured *perceived maximum reaching height* and participants' RPE. On *Day 4*, participants climbed 10 trials. On this day, we determined participants' *actual maximum reaching height* and their RPE before climbing, and after every second trial, thus providing a measure of the participants' actual action capabilities as a function of exertion.

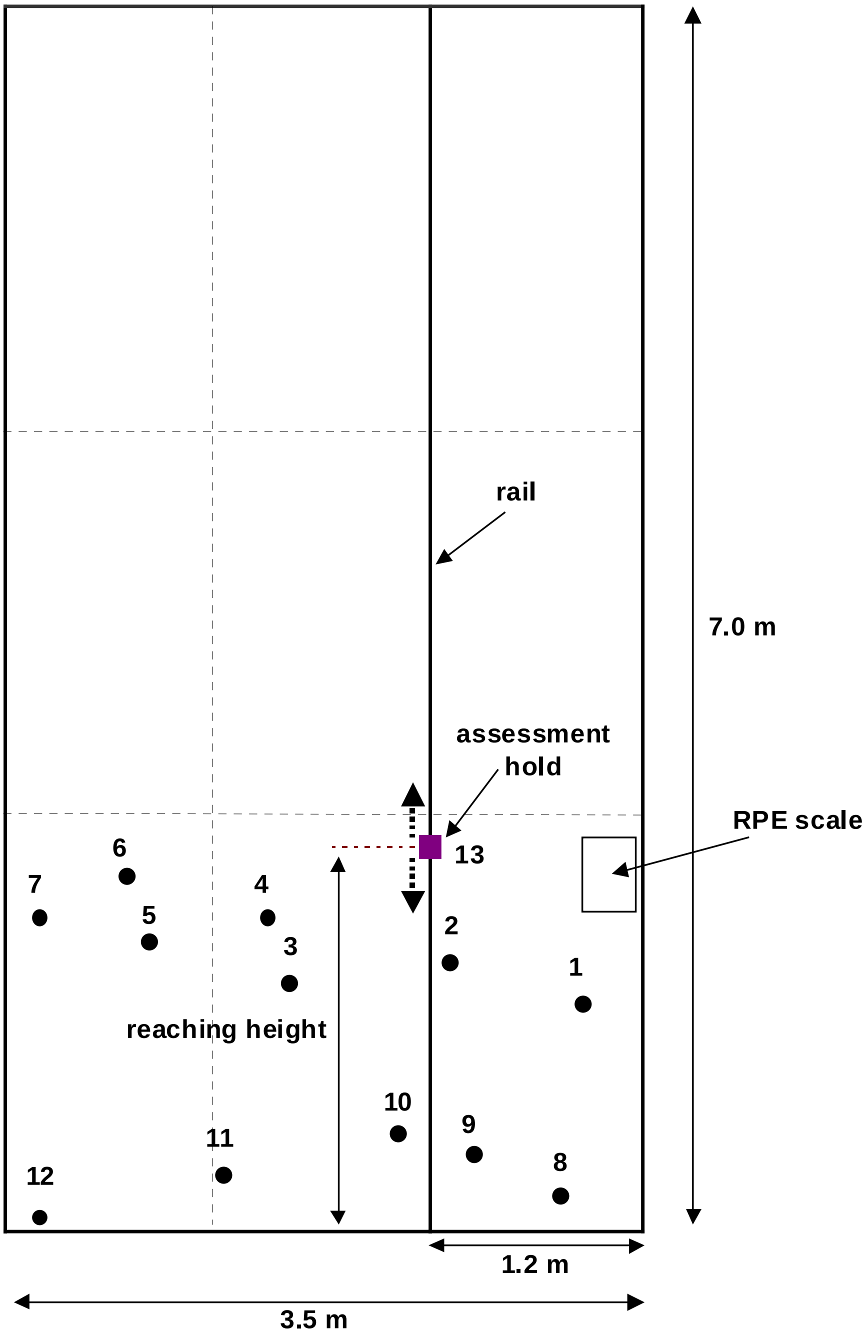

Figure 5.1. *Front view of the layout of the climbing wall used in Experiments 1 and 2. The positions of the holds are indicated by '●' symbols. The assessment hold (Hold 13, indicated by a '■' symbol) could be moved freely along the rail. Dotted lines and the rail indicate the nine laminate panels.*

Experimental Set-up

Participants climbed on a 3º inclined (leading to backward hanging of the participants) artificial climbing wall (width: 3.5 m, height: 7.0 m; see Figure 5.1), which was placed in a large experimental room. The wall consisted of nine laminate panels with a grey grainy texture for friction. Holds could be bolted anywhere on the wall at relative distances of 0.24 m in horizontal direction, and 0.17 m in vertical direction. On the wall, a horizontal route (or 'traverse'), designed by a professional route designer, was created. The route consisted of 12 holds (five footholds and seven handholds) of varying size and shape, all suitable for novice climbers. The mean height of the five footholds was 0.3 m.

One hold, the 'assessment hold' (Hold 13, see Figure 5.1), was movable in vertical direction. This hold was used to estimate the upper limit that participants perceived they were able to reach (the dependent variable *perceived maximum reaching height*). The assessment hold could be moved freely along a rail, which was placed between the laminate panels of the wall and extended the entire height of the climbing wall (see Figure 5.1). The assessment hold was connected with ropes that could be used to pull it up or down. Reference points in the vicinity of the assessment hold (i.e., attachment locations for the holds, irregularities on the wall, edges of the panels) were removed by covering a part of the climbing wall (0.4 m on both sides of the rail) with tape. (Post hoc interviews indicated that none of the participants had used reference points in making their assessments.) Movements of the assessment hold were recorded on video during climbing (Panasonic, type NV-M5E). Hence, no time was lost to measure the height of the assessment hold so that participants could immediately proceed with climbing after making an assessment.

Photo spectrometry was used to measure the blood lactate concentration (Lange, 1991). A blood sample was taken from the thumb, which was first cleaned with alcohol and then a small puncture in the skin was made with a special sterile needle. Approximately 10 µl arterialised capillary blood was collected in a capillary tube and immediately analysed for blood lactate concentration using the Mini analyser (Lange, 1991).

Participants' perceived exertion was assessed during climbing by means of a Dutch version (Vanden Auweele, 1991) of the 15-graded RPE scale (Ratings of Perceived Exertion) (Borg, 1970, 1982, 1985), rating the task from 6 (*no exertion at all*) to 20 (*maximal exertion*). The RPE scale measures participants' subjective evaluation of the exercise intensity with adequate reliability and validity (Chen et al., 2002; Russell & Weeks, 1994; Schomer, 1987), and refers to "a general or overall perception of effort and exertion" (Borg, 1985, p. 6, see also Footnote 2). Verbal anchors are placed as follows (Borg, 1985): 6 is labelled as *no exertion at all*, between 7 and 8 *extremely light*, 9 *very light*, 11 *light*, 13 *somewhat hard*, 15 *hard (heavy)*, 17 *very hard*, 19 *extremely hard*, and 20 *maximal exertion*. An A3-sized RPE scale was placed on the climbing wall (see Figure 5.1), allowing participants to rate their exertion while standing on the holds.

All participants wore well-fitting climbing shoes (Enduro 954, La Sportiva). Since the standard security procedure in climbing (e.g., Skinner & McMullen, 1993) would be ineffective so low above the ground, participants were not secured.

Procedure

Each participant was tested individually. On *Day 1* participants were first informed in general terms about the procedure of the experiment. They also received a brief explanation of the RPE scale according to the guidelines of Borg (1985) and Noble and Robertson (1996)—that is, participants were told how perceived exertion was defined, how the perceptual range was anchored, the nature and use of the scale was explained, the differentiated ratings were explained, that there were no right or wrong answers, and, finally, possible questions were answered. Participants practised the traverse for a minimum of 10 trials. Although the climbing task was new to the participants when they entered the experiment, the climbing route was very easy and readily learned before actual testing started.

On *Day 2* (2 to 8 days after Day 1), prior to being warmed up and testing, participants were carefully instructed about what was meant by maximum reaching height. Maximum reaching height was defined according to the following reaching action (for numbering of the holds, see Figure 5.1): participants had to place their left foot on Hold 9, right foot on Hold 8, right hand on Hold 1, and left hand on Hold 2, and then imagine that while stretching out upwards as far as possible (keeping both feet on the holds; standing on tiptoe was allowed) the left hand would grasp the assessment hold in such a way that they could hang on it. Participants were not allowed to actually execute the reaching action. The verbal anchors of the 15-points RPE scale were recalled. Just before starting with a series of trials (4, 6, 8, or 10 trials) the assessment of the perceived maximum reaching height was performed twice. The assessment hold (see Figure 5.1) was lowered from halfway the wall and the participants had to verbally indicate when the hold would just be reachable in the prescribed manner. Corrections in upward or downward direction were allowed, until the hold was at the perceived maximum reaching height. Following each separate judgement, participants were asked to look straight ahead to the climbing wall, during which the assessment hold was repositioned to halfway the climbing wall. This procedure to assess the participant's perceived maximum reaching height was repeated once. Participants were given no feedback on the accuracy of their assessments. After this, the perceived exertion was rated. Then, participants started climbing the traverse. During climbing the assessment of the perceived maximum reaching height and the rating of the perceived exertion were repeated after every second trial. After making the final assessments of a particular series of trials, participants returned to a seat and a blood sample was obtained to measure the blood lactate concentration. Blood samples were taken three minutes after climbing.

After the recuperation time of at least one hour (longer if participants indicated that they had not fully recovered), participants climbed another of the remaining three series of trials (for instance, if they had already climbed the 4-trial series they now climbed the 6-, 8-, or 10-trial series).

On *Day 3* (one day after Day 2), the procedure of Day 2 was repeated. The remaining two series of trials were now performed (see also *Design*).

On *Day 4* (1 to 14 days after Day 3) participants' actual maximum reaching height was determined before climbing, and after climbing 2, 4, 6, 8, and 10 trials. Participants stood on the footholds (left foot on Hold 9, right foot on Hold 8), and grasped Hold 1 with their right hand (see Figure 5.1), stretching out as high as possible with their left hand while an experimenter immediately positioned the assessment hold in such a way that hanging on it was just possible. The assessment hold was then secured in that position and it was checked whether the participant could indeed just grasp the assessment hold. This procedure was repeated once. The positions of the assessment hold were again recorded on video so that afterwards participants' maximum reaching height could be determined (see *Experimental set-up*). As with the perceptual judgements, each time after the actual maximum reaching height was established, the perceived exertion was rated.

Data reduction

To establish perceived and actual maximum reaching height a frame-grabber and digitising program (Welter, den Brinker, & van Balkom, 1996) were used to determine the image coordinates of the end position of assessment hold. Image coordinates were translated into real world coordinates using the DLT-method (Direct Linear Transformation; Miller, Shapiro, & McLaughlin, 1980; Shapiro, 1978). As indicated in the procedure, participants estimated their maximum reaching height twice on each occasion. The average of the two values was taken as perceived maximum reaching height. Similarly, actual maximum reaching height was the average of the two measurements that were taken.

Statistical analysis

Blood lactate concentrations were analysed using a one-way analysis of variance (ANOVA) with repeated measures on series (4, 6, 8, or 10 Trials). For each series of trials separately, differences in RPE scores, and perceived and actual maximum reaching height were analysed using one-way ANOVAs with repeated measures on number of trials (varying from 'before climbing' to '10 trials'). Mauchly's test was used to determine whether there was a violation of the assumption of sphericity. If a violation occurred, it was corrected for using Huynh-Feldt procedure before determining whether there were significant differences (Kinnear & Gray, 2000). Pair-wise comparisons using t tests were made to locate significant differences between means when a significant main effect was found. In these cases, we followed the guidelines set forth by 'Simple Interactive Statistical Analysis' (SISA) (see http://home.clara.net/sisa/bonhlp.htm) for using the Bonferroni correction procedure (see Kinnear & Gray, 2002). In essence, SISA allows adding the mean correlation between the outcome variables as a parameter as it is to be expected that a set of Bonferroni adjusted variables will be correlated. This meets the criticism pointed out by for example Jaccard and Wan (1996) that the Bonferroni correction procedure is too conservative, especially when the number of comparisons is large. *P* values are reported on the basis of this SISA Bonferroni method. Effect sizes (*ES*), indicating how many standard deviations the means under consideration differed, were calculated by taking the ratio of the difference between the two means and the mean within cell standard deviation of the means (Mullineaux, Bartlett, & Bennett, 2001). An effect size of 0.2, 0.5, and greater than 0.8 represents small, moderate, and large differences, respectively (Cohen, 1988).

Results

Ratings of perceived exertion

Table 5.1 shows the RPE scores before climbing and during climbing the 4-, 6-, 8- and 10-trial series climbed on *Days 2* and *3*. The *ANOVA* performed on the 4-trial series revealed a significant main effect of number of trials, $F(1.30, 19.53) = 45.50$, $p < .001$, $ES = 1.93$. Pair-wise comparisons revealed that the RPE score had increased significantly after every 2 trials (before climbing versus after 2 trials, and after 2 trials versus after 4 trials, both $t(15)$s > 5.5, both ps < .035, both ESs > 0.88. The analyses of the 6-, 8-, and 10-trial series also revealed significant main effects of number of trials, $F(3, 45 = 115.08$, $p < .001$, $ES = 2.69$, $F(1.43, 21.38) = 70.81$, $p < .001$, $ES = 3.64$, and $F(1.90, 28.55) = 89.18$, $p < .001$, $ES = 5.20$, respectively. Pair-wise comparisons showed that the RPE score was significantly higher after every 2 trials for the 6-, 8-, and 10-trial series, all $t(15)$s > 5.0, all ps < .034, all ESs > 0.80.

The RPE scores on *Day 4*, when the actual maximum reaching height was determined, are also shown in Table 5.1. (Due to illness, the RPE score of Participant 9 was missing.) The *ANOVA* performed on these scores revealed a significant main effect of number of trials, $F(1.60, 22.43) = 100.03$, $p < .001$, $ES = 4.83$. Pair-wise comparisons indicated that the RPE score was significantly higher after every 2 trials, all $t(14)$s > 5.9, all ps < .014, all ESs > 0.86.

To verify whether participants were rested from preceding exertions when they started a new series of trials, we determined participants' RPE before they climbed the first, second, third, and fourth series of trials, and analysed these data with a series (first series, second series) and day (Day 2, Day 3) *ANOVA* with repeated measures on both factors. No significant effects were found, confirming that the recuperation times had been sufficiently long, all Fs < 1.82, all ps > 0.20.

Table 5.1. *Means and standard deviations of the Ratings of Perceived Exertion (RPE scores) for the 4-, 6-, 8-, and 10-trial series on Days 2 and 3 (after the perceptual judgements of maximum reaching height), and for the 10-trial series on Day 4 (after the actual reaches; far right column); Reported are participants' RPE score before climbing and after climbing 2, 4, 6, 8, and 10 trials.*

	RPE scores After the perceptual judgements (Days 2 and 3)				*RPE scores after the actual reaches (Day 4)*
	4-Trial series (n = 16)	*6-Trial series (n = 16)*	*8-Trial series (n = 16)*	*10-Trial series (n = 16)*	*10-Trial series (n = 15)*
Before climbing	8.9 ± 2.1	8.4 ± 1.8	8.6 ± 2.0	8.6 ± 1.9	8.9 ± 1.9
After 2 trials	10.6 ± 1.8	10.4 ± 1.9	10.3 ± 1.9	10.3 ± 1.6	10.5 ± 1.7
After 4 trials	12.5 ± 1.8	12.1 ± 1.7	12.3 ± 1.5	12.0 ± 1.4	12.3 ± 1.6
After 6 trials	-	13.4 ± 1.4	13.6 ± 1.8	13.5 ± 1.0	13.9 ± 1.3
After 8 trials	-	-	14.9 ± 1.5	14.4 ± 0.9	15.3 ± 1.4
After 10 trials	-	-	-	15.4 ± 1.2	16.5 ± 1.6

Blood lactate concentration

Box-plot analyses identified statistical outliers for Participants 2 and 3. The scores for Participant 2 were 2.0, 2.2, *7.5*, and 3.0 mmol.l^{-1} and those of Participant 3 were *7.8*, 3.5, 3.1, and 6.4 mmol.l^{-1} after climbing the 4-, 6-, 8-, and 10-trial series, respectively. Given the other values, it is obvious that the values of 7.5 (Participant 2) and 7.8 (Participant 3) are outliers. Therefore, these two participants were excluded from subsequent statistical analysis of the blood lactate data. Blood lactate concentration was 2.7 (SD = 0.8), 2.9 (SD = 0.7), 3.2 (SD = 0.7), and 3.3 (SD = 0.8) mmol.l^{-1} after climbing the 4-, 6-, 8-, and 10-trial series, respectively. The main effect of series did not reach significance although there was a trend, $F(3, 39) = 2.47$, $p < .10$, $ES = 0.72$.

Taking the RPE and blood lactate data together, it is safe to conclude that exertion progressively increased with increasing number of trials within as well as across the series of climbing trials.

Actual maximum reaching height

Table 5.2 shows the averages and standard deviations of the actual maximum reaching height (due to illness the results of Participant 9 are missing). An *ANOVA* with repeated measures on the actual maximum reaching heights comparing maximum reaching height before climbing, and after 2, 4, 6, 8, and 10 trials did not show a significant main effect of number of trials, $F(3.18, 44.52) = 1.48$, $p > .10$.

Table 5.2. *Means and standard deviations of the actual maximum reaching height for the 10-trial series on Day 4, and of the perceived maximum reaching height for the series of 4-, 6-, 8-, and 10-trial series on Days 2 and 3, Reported are participants' actual and perceived maximum reaching height before climbing, and after climbing 2, 4, 6, 8, and 10 trials.*

	Actual maximum reaching height[a] *(Day 4)* *(n = 15)*	*Perceived Maximum Reaching Height*[a] *(Days 2 and 3)*			
		4-Trial series (n = 16)	*6-Trial series (n = 16)*	*8-Trial series (n = 15)*	*10-Trial series (n = 14)*
Before climbing	212.7 ± 9.0	219.4 ± 10.7	221.3 ± 12.6	220.7 ± 15.0	221.5 ± 13.9
After 2 trials	214.0 ± 8.7	218.6 ± 11.5	218.6 ± 12.5	218.6 ± 15.3	219.6 ± 14.1
After 4 trials	213.4 ± 8.6	215.9 ± 11.8	217.0 ± 14.1	216.6 ± 13.2	217.6 ± 13.4
After 6 trials	213.0 ± 9.2		215.8 ± 14.4	215.8 ± 16.0	216.6 ± 14.2
After 8 trials	212.9 ± 9.1			216.4 ± 14.5	216.1 ± 15.0
After 10 trials	212.7 ± 8.5				216.2 ± 14.6

[a]In cm.

Perceived maximum reaching height

Table 5.2 also shows the perceived maximum reaching heights for the series of 4, 6, 8, and 10 climbing trials. Note that the number of participants varied for the different statistical analyses due to technical failure of the camcorder and misinterpretation of the assessment task by one of the participants on *Day 2*. Furthermore, it is important to realize that the large standard deviations reported in Table 5.2 result from the varying heights of the participants, a source of variance that is separated from the variance due to the independent variable (i.e., level of exertion) in the statistical tests (e.g., Kinnear & Gray, 2000).

For the 4-trial series a significant main effect was found on number of trials, $F(1.47, 22.08) = 7.38$, $p < .05$, $ES = 0.31$. Pair-wise comparisons using t tests revealed that after climbing 4 trials perceived maximum reaching height was significantly lower than before climbing, $t(15) = 3.0$, $p < .047$, $ES = 0.31$, and after climbing 2 trials, $t(15) = 2.6$, $p < .047$, $ES = 0.23$.

For the 6-trial series there was also a significant main effect of number of trials, $F(1.94, 29.05) = 5.91$, $p < .05$, $ES = 0.41$. Pair-wise comparisons showed that perceived maximum reaching height after climbing 2, 4, or 6 trials was lower than before climbing, all $t(15)$s > 2.7, all ps < .043, all ESs > 0.21. After climbing 6 trials perceived maximum reaching height was significantly lower than after climbing 2 trials, $t(15) = 2.09$, $p < .043$, $ES = 0.21$.

The analysis of the series of 8 trials also yielded a significant main effect of number of trials, $F(4, 46) = 4.01$, $p < .05$, $ES = 0.33$. In this series of trials, perceived maximum reaching height was significantly lower after climbing 4, 6 or 8 trials than before climbing, all $t(14)$s > 2.4, all ps < .043, all ESs > 0.29). After climbing 4 or 6 trials, perceived maximum reaching height was significantly lower than after climbing 2 trials, both $t(14)$s > 2.0, both ps < .043, both ESs > 0.14).

Finally, for the 10-trial series there was also a significant main effect of number of trials, $F(3.56, 46.25) = 7.23$, $p < .001$, $ES = 0.38$. After climbing 4, 6, 8, or 10 trials, perceived maximum reaching height appeared to be lower than before climbing, all $t(13)$s > 3.3, all ps < .044, all ESs > 0.28). In addition, after climbing 4, 6, 8, or 10 trials participants assessed their maximal reach lower than after climbing 2 trials, all $t(13)$s > 2.5, all ps < .044, all ESs > 0.14).

Figure 5.2 provides a graphical summary of the findings of the actual and perceived maximum reaching height across the series of climbing trials. As can be seen, the actual maximum reaching height remained fairly constant across the number of trials climbed. The perceptual changes were most prominent when participants were not yet fatigued, and it appears that for the higher levels of exertion perceived maximum reaching height levels off.

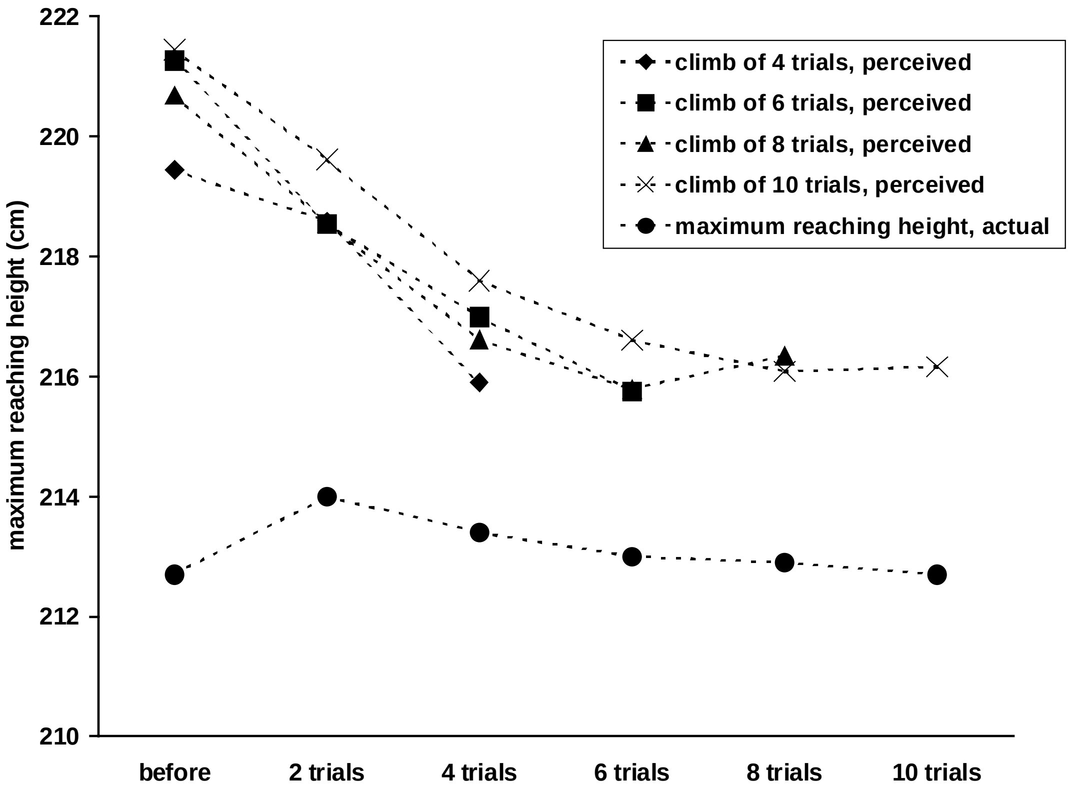

Figure 5.2. *Perceived maximum reaching height (in cm) for the series of climbs of 4, 6, 8, and 10 trials, and actual maximum reaching height (in cm).*

Discussion

Actual maximum reaching height did not decrease as the number of trials climbed increased. Thus it seems that actual action capabilities were not affected as levels of exertion increased. Perceived maximum reaching height did decrease as perceived exertion increased. The more fatigued the participants were, the lower their perception of maximum reaching height seemed to be (see also Figure 5.2). Note, however, that the perceived maximum reaching height decreased especially in the beginning of the climbing task and not at the end when higher levels of perceived exertion were reported. After climbing two trials of which the exercise intensity was rated as *very light* to *light* (9 and 11 on the RPE scale, respectively; see Table 5.1), the perceived maximum reaching height already decreased substantially (see Table 5.2). Moreover, the perceived maximum reaching height after climbing six or more trials—accompanied by RPE scores of 13 (*somewhat hard*) to 15 (*hard, heavy*)—appeared to level off (see Figure 5.2). This suggests that the changes in perceptual judgements that were found in this experiment were not stringently related to participants' higher levels of physical fatigue. At the higher levels of perceived exertion, neither perceived nor actual maximum reaching height decreased (see also Figure 5.2), which is in accordance with the view that judgements of maximum reaching height will only decrease when the actual action capabilities are also affected.

A possible explanation for the finding that the perceived maximum reaching height mainly decreased already after 2 and 4 trials and less after 6, 8, and 10 trials might be that as participants gain experience in climbing the traverse, they learned to pick up the relevant information in order to successfully execute the perceptual task. Although the experimental design, with participants climbing the 4-, 6-, 8-, and 10-trial series in different orders (and on different days), was intended to correct for order effects, short-term calibration effects (e.g., Jacobs, 2001; Jacobs & Michaels, 2002; Withagen & Michaels, 2002) might still have played a role. To investigate this we calculated participants' averaged perceived maximum reaching height before they climbed the first, second, third, and fourth series of trials. If the decrease in maximum reaching height after 2 and 4 trials is attributable to brief hands-on experience with the task, then at least lower scores of perceived maximum reaching height are expected when participants performed the second series of trials than when they performed the first series of trials. What should be expected for the third and fourth series of trials (relative to series one and two) is unclear as they were climbed on another day than series one and two.

We tested the effects of series (first series, second series) and day (Day 2, Day 3) with a two-factor *ANOVA* with repeated measures on both factors. It appeared that participants judged their maximum reaching height to be significantly lower in the second series of trials (mean [M] = 219.0, SD = 13.3 cm) than in the first series of trials (M = 221.2, SD = 12.4 cm), $F(1, 13) = 5.08$, $p < .05$, $ES = 0.17$. The average perceived maximum reaching height did not differ significantly between Day 2 and Day 3, $F(1, 13) = 1.32$, $p > .10$, and the interaction between series and day was also not significant, $F < 1$. Apparently the effect of series was present on both days, suggesting that participants benefited, at least in the short run, from previous experiences with the task at hand. The brief hands-on experience with the task may have yielded perceptual information about climbing actions, which allowed calibration and led to changes in perceived maximum reaching height. In the *General Discussion* we return to this issue.

The design of Experiment 1 was largely dictated by our wish to manipulate exertion in a controlled manner. Therefore, all participants also climbed a maximum of 10 trials, which yielded exertion levels close to exhaustion in pilot testing. However, in the experiment itself the 10 climbing trials did not produce exhaustion in the majority of the participants, although many of them indicated that exertion was *hard* to *very hard* after climbing the tenth trial. Thus, it remains to be seen what the effects of exhaustion are on perceived and actual maximum reaching height in the current setting. Therefore, in Experiment 2 we asked another group of participants to climb to exhaustion, and we collected data about participants' perceived exertion, and perceived and actual maximum reaching height at increasing levels of exertion.

Experiment 2

The aim of Experiment 2 was to further investigate whether and how perceptual judgements change as a function of exertion and action capabilities by including exhaustion trials. In Experiment 2 participants climbed twice, once to determine perceived maximum reaching height, and a second time to determine actual maximum reaching height as a function of exertion. As in Experiment 1, we expected that the RPE scores would increase with the number of trials climbed. Furthermore, we expected that exhaustion would lower the actual and consequently the perceived maximum reaching height.

Method

Participants

A total of 16 female participants (aged 18 to 29 years), mainly college students, volunteered to participate in the experiment. None of them had participated in Experiment 1. Participants had little or no experience in climbing, and were naive to the purpose of the experiment. All participants signed a written informed consent, and were paid a small fee for their participation. The study's protocol was formally approved by the Local Ethics Committee of the Faculty of Human Movement Sciences before the experiment was conducted.

Experimental Set-up

Participants climbed on the same climbing wall as in Experiment 1 (see Figure 5.1). This time the wall was not inclined but vertical, because now there was no need to attempt to restrict the climbing duration. In Experiment 1 perceived maximum reaching height was assessed with 'descending trials' only (i.e., the assessment hold was lowered) while usually a combination of descending and ascending trials is used for such perceptual measurements (e.g., Pufall &

Dunbar, 1992).[3] As climbing duration was no longer a serious constraint this was now also done in Experiment 2. The position of Hold 2 (see Figure 5.1) was slightly changed so as to make ascending trials possible as well. Time now also allowed perceived and actual maximum reaching height to be measured each time by means of a tape measure. Again, the Dutch version of Borg's RPE scale (Vanden Auweele, 1991) provided an index of each participant's perceived effort before climbing and after climbing every second trial. As the RPE scores seemed to be sufficient to establish gradual changes in participants' perceived exertion, blood lactate was not measured in Experiment 2. Participants wore well-fitting climbing shoes and were not secured. All climbs were videotaped using an S-VHS camcorder (sampling rate of 50 Hz) allowing inspection of specific aspects of the experiment when needed.

Procedure

For each participant (tested individually) the experiment was spread over two days. On *Day 1* participants were familiarized with the experiment. They received a brief explanation of the RPE scale, and they were instructed about what was meant with maximum reaching upon which they had to base their judgements of maximum reaching height (see Experiment 1). Then they did an 'off-the wall' warming up, as we did not want to provide them with a brief hands-on experience with the climbing task. After the warming up participants climbed until exhaustion. As in Experiment 1 we measured perceived maximum reaching height and participants' RPE before climbing and after climbing every second trial. Each time perceived maximum reaching height was assessed twice. The assessment hold (see Figure 5.1) was lowered from halfway the wall, and the participants had to verbally indicate when the hold would just be reachable in the prescribed manner (*descending trial*) (see Experiment 1). Perceived maximum reaching height was determined to the nearest millimetre. Subsequently the assessment hold was pulled up from the bottom of the wall (*ascending trial*) and perceived maximum reaching height was determined again. The descending and ascending trials were presented in alternating order. Again, participants were given no feedback on the accuracy of their assessments. After each couple of assessments, the perceived exertion was rated. Participants continued climbing until exhaustion. When they rated the exercise as *extremely hard*, score 19 on the RPE scale, they were urged to climb another two trials whereupon the perceived maximum reaching height was determined for the last time. After that, participants stopped climbing.

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[3] It is known that participants tend to perceive their maximum reaching height as greater on descending trials than on ascending trials (Pufall & Dunbar, 1992). Pufall and Dunbar (1992) considered this direction effect as a performance characteristic of perceptual functioning: it is an indication of within-observer variability and is "... systematically related to how the obstacle moves through the visual world, and correspondingly how it is tracked by the visual system" (p. 32).

On *Day 2* (5 to 21 days after *Day 1*) participants' actual maximum reaching height was determined (see Experiment 1) before climbing, and after climbing every second trial until exhaustion. Each time after the actual maximum reaching height was established twice, the perceived exertion was rated. As with the perceptual judgements, when participants rated the exercise as *extremely hard*, they were encouraged to climb another two trials whereupon the actual maximum reaching height was determined for the last time. After that, participants stopped climbing.

Data reduction

Each time the average of the descending and ascending trials was taken as perceived maximum reaching height for that moment. Similarly, actual maximum reaching height was the average of the two measurements that were taken each time.

Statistical analysis

RPE scores were analysed with a day (Day 1, Day 2) by number of trials (before climbing, after 2, 4, 6, and 8 trials, and after exhaustion) ANOVA with repeated measures on both factors. Perceived and actual maximum reaching height were analysed using one-way ANOVAs with repeated measures on number of trials (before climbing, after climbing 2, 4, 6, and 8 trials, and after exhaustion). (See also *Results* for explaining the number of trials analysed.) Violations of the assumption of sphericity were treated in the same manner as in Experiment 1. Again, the Bonferroni correction procedure was used, and effect sizes were calculated (see Experiment 1).

Results

To investigate the differential effects of progressively increasing levels of exertion, we considered it necessary to have at least six data points to achieve a continuum of exertion. Therefore, participants had to climb at least 10 trials so that we had measurements before climbing, after climbing 2, 4, 6, and 8 trials, and after exhaustion. Three participants who were unable to climb the required 10 trials were excluded from further analyses. All three had ceased their efforts because of muscle cramp. On *Day 1* the number of trials after which exhaustion was reported ranged from 10 to 82 trials, with an average of 21.8 trials (SD = 20.4), and on Day 2 it ranged from 10 to 50 trials, with an average of 22.0 trials (SD = 13.1).[4] An overview of the results is presented in Table 5.3.

[4] The large difference in the maximum number of trials climbed on *Days 1* and *2* can be ascribed to one participant who had climbed no less than 82 trials on *Day 1* and 38 trials on *Day 2*. As there was no reason to exclude her from the analyses other than the extremely large number of trials climbed on *Day 1*, this participant was included in the analyses reported. Excluding her yielded a similar pattern of results.

Ratings of perceived exertion on Days 1 and 2

The *ANOVA* performed on the RPE scores (see Table 5.3) revealed a significant main effect of Day, $F(1, 12) = 12.37$, $p < .05$, $ES = 0.98$. On average, participants reported significantly higher RPE scores on *Day 1* ($M = 15.2$, $SD = 1.1$) than on *Day 2* ($M = 13.8$, $SD = 1.7$). The main effect for number of trials was also significant, $F(2.49, 29.87) = 138.81$, $p < .001$, $ES = 6.65$, indicating that the RPE score was significantly higher after every two trials, all $t(12)$s > 6.2, all *p*s < .011, all *ES*s > 0.66.[5] There was also a significant Day × Number of Trials interaction, $F(3.45, 41.34) = 3.96$, $p < .05$, $ES = 6.33$, which mainly occurred because the difference in RPE scores between *Days 1* and *2* did no longer exist at the end of climbing when exhaustion was reported and, thus, all RPE scores (both on *Day 1* and *Day 2*) are 20 (see Table 5.3).

Table 5.3. *Means and standard deviations of the variables Ratings of Perceived Exertion (RPE scores) and actual maximum reaching height on Day 2, and of the variables Ratings of Perceived Exertion (RPE scores) and perceived maximum reaching height on Day 1. Reported are participants' RPE score, actual and perceived maximum reaching height before climbing, and after climbing 2, 4, 6, 8, and 10 trials (Experiment 2).*

	Day 2		*Day 1*	
	RPE scores	*Actual maximum reaching height*[a]	*RPE scores*	*Perceived maximum reaching height*[a]
Before climbing	9.5 ± 2.4	212.6 ± 5.9	11.1 ± 1.4	221.3 ± 9.7
After 2 trials	11.3 ± 2.3	214.0 ± 5.0	12.8 ± 1.1	217.1 ± 11.9
After 4 trials	12.8 ± 2.3	213.8 ± 4.9	14.5 ± 1. 5	218.2 ± 11.2
After 6 trials	14.2 ± 2.3	212.4 ± 5.5	15.8 ± 1.8	216.7 ± 10.4
After 8 trials	15.4 ± 2.3	212.1 ± 4.3	17.2 ± 2.0	214.4 ± 10.0
After exhaustion	20[b]	210.7 ± 6.8	20[b]	210.9 ± 12.5

[a]In cm.

[b]Participants stopped climbing, when they rated their exertion as 'maximal' (RPE score: 20) so no standard deviation is computed.

Actual maximum reaching height

Analysis of the actual maximum reaching height (see also Figure 5.3) revealed a significant main effect of number of trials, $F(3.40, 40.75) = 3.77$, $p < .05$, $ES = 0.60$. Pair-wise comparisons showed that after climbing to exhaustion, participants' actual maximum reaching height was significantly lower than after climbing 2 or 4 trials, both $t(12)$s > 3.6, both *p*s < .034, both *ES*s > 0.53. In addition, participants reached significantly lower after climbing 6 or 8 trials than after climbing 2 or 4 trials, all $t(12)$s > 2.2, all *p*s < .034, all *ES*s > 0.27. In sum, very high levels of exertion affected participants' actual maximum reaching.

[5] Recall that the reported *p* values are on the basis of the SISA Bonferonni method (see *Statistical Analysis* section of Experiment 1).

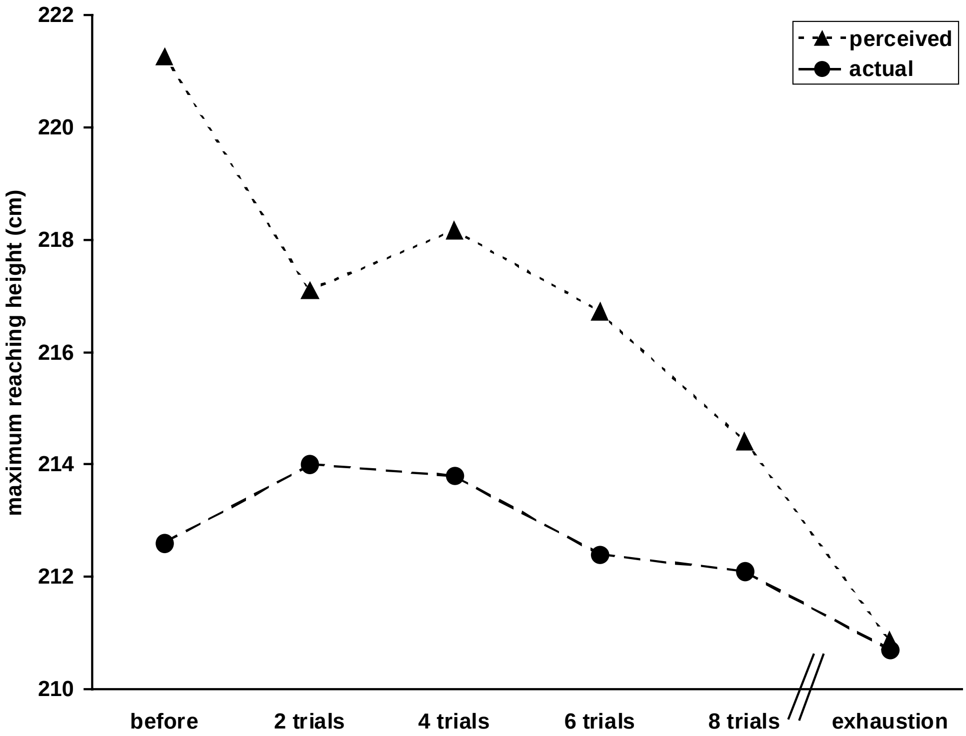

Figure 5.3. *Perceived maximum reaching height (indicated by '▲' symbols), and actual maximum reaching height (indicated by '●' symbols), before climbing, after climbing 2, 4, 6, and 8 trials, and after climbing to exhaustion (in cm) (Experiment 2).*

Perceived maximum reaching height

Figure 5.3 illustrates participants' perceived maximum reaching height (see also Table 5.3). Analysis of the perceived maximum reaching height yielded a significant main effect of number of trials, $F(3.06, 36.71) = 7.54$, $p < .001$, $ES = 0.95$.[6] Pair-wise comparisons showed that the perceived maximum reaching height after climbing 2, 6, or 8 trials, and than after climbing to exhaustion was significantly lower than before climbing, all $t(12)$s > 2.3, all *p*s < .032, all *ES*s > 0.38. In addition, participants perceived their maximum reach to be significantly lower after climbing to exhaustion than after climbing 2, 4, and 6 trials, all $t(12)$s > 2.5, all *p*s < .032, all *ES*s > 0.50. The perceived maximum reaching height after climbing 8 trials was significantly lower than after climbing 4 and 6 trials, both $t(12)$s > 2.1, both *p*s < .032, both *ES*s > 0.22. No significant differences were found in perceived maximum reaching height after having climbed 4 trials compared to having climbed 2 trials, and after having climbed 6 trials compared to having climbed 4 trials, both $t(12)$s < 1.7, *p*s > .032). The

[6] Given the change from using descending trials only in Experiment 1 to a combination of descending and ascending trials in Experiment 2, it is important to note that the pattern of results is similar when descending or ascending trials are analysed separately.

difference between 8 trials and exhaustion was not statistically significant, $t(12) = 1.6$, $p > .032$.

Discussion

As in Experiment 1, each time participants climbed another two trials they reported more exertion than before climbing the two trials, which indicates that the manipulation of exertion was successful. For levels of exertion perceived as *light* (RPE score about 11) to *hard* (RPE score about 15), participants' actual maximum reaching height was not affected. At higher levels of exertion and after exhaustion participants' actual maximum reaching height was affected leading to lower reaches. The changes in actual maximal reaching height may seem small (range 210.7 cm to 214.0 cm), but note that the actual range of reachability is probably closer to, say, 40 cm (i.e., maximum reaching height minus physical height) or even less. Even when exhausted, one will still at least succeed in raising one's hand above one's head. In that light, the observed decrease in actual maximum reaching height is both substantial and meaningful, as it may, for instance, be decisive in whether a route can be climbed or not.

As in Experiment 1, the perceived maximum reaching height decreased particularly in the beginning of the climbing task (see Figure 5.3) when fatigue had not yet set in. In addition, for levels of exertion perceived as *light* (RPE score about 11) to *hard* (RPE score about 15), the perceived maximum reaching height did not change. At the moment that exercise intensities were rated, on average, as *very hard* and higher (RPE score 17 and higher), the perceived maximum reaching height again declined significantly (see Table 5.3). Overall, these findings seem to indicate that changes in perceived maximum reaching height followed changes in actual maximum reaching height rather than changes in exertion.

General Discussion

In the present study, we examined the relationship between perception of action possibilities, actual action capabilities, and progressing levels of exertion in the context of wall climbing. Three parts of this relationship became apparent in the results of Experiments 1 and 2 (see Figures 5.2 and 5.3): First, when participants were not yet fatigued a rapid decrease in perceived maximum reaching height occurred while the actual maximum reaching height remained constant. Second, levels of exertion rated as *light* (RPE score about 11) to *hard* (RPE score about 15), neither affected the actual nor the perceived maximum reaching height. Third, when exertion was rated as *very/extremely hard* (RPE score 18/19) to *maximal exertion* (RPE score 20), participants' actual maximum reaching height declined, which was accompanied by a decrease in their perceived maximum reaching height. It is useful to discuss each of these parts in detail.

First, brief hands-on experience with the task (see *Discussion* of Experiment 1) seems to be responsible for the early changes in perceived maximum reaching height that were found in both experiments. Scaling of perceptual judgements on the basis of exploratory behaviour was also reported by Mark (1987), who found that after a change in eye-height of 10 cm observers quickly recalibrated their judgements of maximal sitting and stepping height when they were allowed to move and employ information-gathering activities such as locomotion and head turning. In climbing the first few trials, the participants in the present experiments may have calibrated their actions in relation to their environment leading to more accurate (lower) judgements of maximum reaching height after climbing two trials. This adaptation appeared to be functional because participants started with apparent overestimations. Furthermore, the adaptation in question occurred each time anew as is apparent from the fact that calibration effects were visible on the different testing days (see also *Discussion* of Experiment 1).

Second, light to hard levels of perceived exertion affected neither actual nor perceived maximum reaching height. Thus, although the physical state of the participants changed in that they became more fatigued, it did not affect their judgements of maximum reaching height, which again seemed to be functional, as the participant's action capabilities remained unaffected.

Third, as soon as changes in participants' action capabilities occurred, as was the case when perceived exertion was rated as *very hard* to *maximal exertion*, changes in perception of action possibilities were also apparent. Thus, perceived maximum reaching height seemed to follow changes in actual maximum reaching height, rather than the state of physical fatigue of the observer.

These results indicate that changes in perceived exertion are not necessarily related to changes in perception of action possibilities. Changes in the perception of action possibilities only occur when changes in participants' actual action capabilities have occurred. Thus, the perception of the environment in terms of action possibilities does not change when the observer is, for instance, somewhat fatigued, anxious, or hungry. Dropping for a moment the conceptual self-embargo of Footnote 1, our findings are consistent with Gibson's (1979) original ideas about affordances that a change in need or state of the observer does not immediately alter affordances, and hence, the perception of affordances. Only as soon as the observer's action capabilities are affected, for instance, when exhausted, the perception of the action possibilities is affected as well.

This does not imply that changes in an observer's state or need without changes in action capabilities have no effect at all on the perception and realization of affordances. A person's internal state plays an important role in the selection of affordances as people have to select which affordances they wish to realize among the many that are afforded by the environment, depending on their intentions (Gibson, 1979; Michaels, 2003; Stoffregen, 2003). It is very likely that people's intentions, and hence, the selection of affordances, are constrained by the person's state or need. As Gibson (1979) put it "The observer may or may not perceive or attend to the affordance, according to its needs, but the affordance, being invariant, is always there to be perceived" (p. 139). Thus, the state or need of an observer is of relevance in constraining the choice of action modes to achieve a particular goal (Mark et al., 1997; Stoffregen, 2003).

It is important to note that the functional relationship between actual action capabilities and perceived action possibilities does not mean that absolute values of the estimations should be a perfect match of the actual action capabilities. Just as in other research into the perception of reaching possibilities (e.g., Bootsma et al., 1992; Carello et al., 1989; Heft, 1993; Pepping & Li, 1997; Pufall & Dunbar, 1992), reaching height was generally overestimated in our study. In this respect, Heft (1993) showed that verbal judgements of action possibilities invite an analytical attitude transforming what is typically a skilled, unreflective perception-action process, into a reflective judgement. When judgements of reach were a means to complete another task the analytical attitude was circumvented and the assessments of perceived reach were more accurate (Heft, 1993).

As an aside, this seems to be in accordance with recent findings that there are two anatomically distinct streams for visual information processing, the ventral and the dorsal stream, each serving quite different functions dubbed vision for perception and vision for action, respectively (e.g., Milner & Goodale, 1995; Goodale & Haffenden, 1998). Vision for perception is mainly concerned with representing the world, that is, the explicit knowledge of environmental properties. Vision for action is primarily concerned with the control of action in the environment (Goodale & Haffenden, 1998; Goodale & Humphrey, 1998; Milner & Goodale, 1995; Norman, 2002). By implication verbal judgements would tap the ventral rather than the dorsal stream providing 'information for perception' that is not necessarily accurate (Goodale & Humphrey, 1998; van der Kamp, Savelsbergh, & Rosengren, 2001). Vision for action, as supported by dorsal stream activity, should be accurate and requires "veridical evaluation of the surface layout for effective interaction with the immediate environment" (Bhalla & Proffitt, 1999, p. 1093). The use of verbal reports in our study may have contributed to the overestimations of maximum reaching height.

Conclusions

Our study supports two main conclusions. First, early during task execution when fatigue was not yet present, changes in perceived maximum reaching height already occurred. The brief hands-on experience with the task may have produced or exposed relevant perceptual information about climbing actions, which allowed calibration to occur and led to changes in perceived maximum reaching height. Second, and most important for the present study, there appears to be a functional fit between participants' actual action capabilities rather than their physical state of fatigue and perceived action possibilities. Apart from the early changes, perceived maximum reaching height followed the changes in action capabilities. When there were no such changes (at moderate levels of perceived exertion), no changes in perceived action possibilities occurred. Only when actual maximum reaching height changed (i.e., at higher levels of perceived exertion), this was reflected by perceptual changes. Thus, only at the higher and not for lower levels of exertion, perceptual judgements about action possibilities may change.

Acknowledgements

We dedicate this study to the memory of Floris Holsheimer, 1970-2005, who played an important role in executing Experiment 1. In addition, we thank David Samoocha for his assistance in conducting Experiment 2, and Peter Beek and two anonymous reviewers for helpful comments on an earlier draft of the paper.

Chapter 6

Epilogue

Introduction

In the preceding chapters, a series of experiments was reported aimed at furthering our understanding of the impact of state variables (i.e., anxiety and fatigue) on human motor performance. As it was important to find an adequate and expedient way to manipulate anxiety, climbing on an indoor climbing wall was chosen as experimental task (see Chapters 2-4). This task also provided a natural context to manipulate fatigue (Chapter 5). The aim of this epilogue is to review a selection of the results with an eye for future directions in studying effects of anxiety on human motor performance. First, I will summarize the major findings of Chapters 2-5.

Summary of the main results of Chapters 2-5

The studies reported in Chapters 2 and 3 were done from a process-oriented approach in order to identify the effects of anxiety on physiological, psychological and behavioural processes underlying task performance, rather than task performance per se.

Chapter 2 reported two experiments that were conducted to study manifestations of anxiety at the subjective, physiological and behavioural level of analysis. Anxiety was manipulated in novice climbers by using a climbing wall with routes defined at different heights (low and high), while self-reported state anxiety, heart rate, blood lactate concentration and muscle fatigue, movement fluency, and climbing time were measured. When novice climbers climbed the high route on the climbing wall they subjectively reported significantly more anxiety than when they traversed the same route low on the climbing wall. At the physiological level, they exhibited significantly higher heart rates, more muscle fatigue, and higher blood lactate concentrations (climbing times were standardised). Furthermore, state anxiety also affected the movement behaviour of the participants in that a geometric index of the entropy of their trajectories as well as their climbing times increased. Indeed, anxiety manifested itself at all three levels, and it was tentatively concluded that anxiety induces a temporary regress to a form of movement execution that is associated with earlier stages of motor learning.

Chapter 3 also focused on the impact of anxiety on movement behaviour at the climbing wall using novice climbers as participants. Masters' (1992) conscious processing hypothesis suggests that under pressure an inward focus of attention occurs, resulting in more conscious control of the movement execution of well-learned skills, resulting in turn in interference with automatic task execution and performance decrements. Recent empirical support for this hypothesis was found in terms of the effects of pressure on end performance. The present study tested whether the changes in performance were also accompanied by changes in movement execution, as would be expected from Masters' hypothesis. Again, two identical traverses at different heights on a climbing wall were used to create different anxiety conditions. In line with the conscious processing hypothesis, it was found that anxiety had a significant effect on participants' movement behaviour in that climbing time and the number of explorative movements were increased (Experiments 1 and 2), holds were grasped longer and movements between holds were slower (Experiment 2). As such, the results provided additional support for the conscious processing hypothesis as well as insight into the relations among anxiety, performance, and movement behaviour.

Chapter 4 reported three experiments on the relation between anxiety and perception, again in the context of climbing with identical traverses situated high and low on a climbing wall to manipulate anxiety, and using novices as participants. In Experiment 1 participants judged their maximal overhead reachability and made maximal reaches on the climbing wall. Increased anxiety was found to reduce both perceived and actual maximum reaching height. The second experiment tested whether these perceptual changes were also accompanied by changes in participants' selection of action possibilities (affordances) and, consequently, overt movement behaviour. As before, two identical traverses at different heights (low and high) on a climbing wall were used to manipulate anxiety. Participants climbed from right to left and back on the high and low traverses, which now entailed an abundance of holds. Elevated (self-reported) anxiety led to increases in climbing time, as well as the number of holds used, consistent with the reduction of perceived and actual maximum reaching height found in Experiment 1. In order to gain more insight into the attentional mechanisms that might underlie the anxiety-induced changes in perception and realization of action possibilities that were found in Experiments 1 and 2, points of lights were sequentially projected around the participants while they were climbing in the third experiment. As participants detected less lights in the high-anxiety condition, it was concluded that anxiety narrowed attention. In general, the results underscored that the actor's emotional state affects the perception and realization of affordances in a manner that is consistent with the changes that accompany this emotional state, such as changes in actual action capabilities and attention.

For obvious reasons, experimental manipulation of the state variable anxiety is more limited in evoking extreme changes in mood state than a state variable such as fatigue. In *Chapter 5* we therefore reported an attempt to generalize the conclusions of Chapter 4, regarding the relationship between anxiety and perception, to fatigue. In the first experiment, novices had to complete the same traverse on a climbing wall a given number of times (up to 10 trials), in order to induce increasing levels of exertion. Before and during climbing participants judged their maximum reaching height, as well as perceived exertion. On a separate day, they climbed another 10 trials and performed actual maximum reaches during climbing. Higher levels of perceived exertion were correlated with decreases in perceived maximum reaching height while actual reaching height remained constant. However, the perceptual changes were found predominantly early during task execution when participants were not yet fatigued. When fatigue kicked in neither perceived nor actual maximum reaching height was affected. Contrary to the expectations of pilot testing, however, not all participants reached exhaustion after climbing 10 trials. Therefore, in Experiment 2 exhaustion trials were included. The findings replicated the early changes in perception, which may have resulted from task adaptation, also referred to as calibration. Furthermore, while climbing to exhaustion, perceptual judgements now changed largely in accordance with changes in the actual maximum reaching height. In keeping with Chapter 4, these findings were interpreted to imply the existence of a functional relationship between participants' actual action possibilities, rather than their state of physical fatigue per se, and perceived action possibilities.

The impact of anxiety on human motor performance

Chapters 2 and 3 showed that anxiety affects a plethora of subjective, physiological and behavioural processes that contribute differentially, and probably interactively, to the resulting performance. We found changes in self-reported state anxiety, heart rate, blood lactate concentration, muscle fatigue, movement fluency, and climbing time. In addition, the number of exploratory movements changed, as did the time participants grasped the holds and moved from hold to hold. Anxiety was also found to reduce both perceived and actual maximal reaching height, which constrained the choice of behaviour evidenced by the use of a different number of holds when climbing a route in both anxiety conditions. Finally, we found indications that anxiety induced attentional narrowing.

Thus, a number of changes due to anxiety have been identified on different levels of analysis, which at the level of human action can be summarized as changes in the perception and selection of affordances. This leads to the question how the actor's emotional state affects the selection of affordances, as the commonplace situation is that the environmental layout affords multiple actions for achieving a particular goal. To give an example of the presence of multiple affordances, for some people a vertical wall affords climbing provided it has sufficient irregularities to be grasped and to stand on. For others, the wall hardly affords climbing and, if it does, other possibilities for action come to the fore: jumping back to the safe floor or, a less attractive possibility, falling down. The same ambiguity can be observed when individuals are in a safe or unsafe environment. When individuals stand on the floor, the holds on the wall within reach of the individual provide opportunities to step on or cling onto. However, situated a few metres above the floor these opportunities are less readily appreciated: one can slip off the hold or fail to reach the grip. Thus, how is behaviour constrained under anxiety conditions? I will elaborate on that issue in the next subsection.

'State-scaled' information about affordances

A critical issue in Gibson's (1979) theory is the question of how the concept of affordances constrains perception and behaviour (Cutting, 1982; Fodor & Pylyshyn, 1981; Hardy & Jones, 1994; van Wieringen, 1988), or in other words, how affordances are selected. Evidently, the problem of affordance selection is inevitable. Cutting (1982) exemplifies this by listing what a piece of paper affords and concluded that "... it quite simply affords all the possible things I can do with it" (p. 216). In order to apply the theory of affordances, it seems critical to resolve the problem of selection or choice (e.g., Mark et al., 1997). Is the perception of affordances influenced by affective and cognitive factors such as anxiety? Or is a more parsimonious explanation available without using these concepts? For example, Jiang, Mark, Anderson, and Down (1993) and Jiang and Mark (1994) provided an elegant explanation for their finding that participants' estimates of crossable gap width decreased as gap depth increased by showing that estimates of gap crossing capability depended decisively on where observers directed their gaze: when looking down into the gap, participants tended to underestimate their capabilities more than when they looked at the horizon. Thus, Jiang and colleagues disputed that emotional (or analytical) processes caused the more conservative assessments they had found in their study. Their explanation, however, does not exclude the possibility that gaze direction and emotional processes covaried, that is, when participants looked down into the gap they may have felt fear of the depth resulting from the increased risk to their safety. When they looked at the horizon participants may have felt no or less fear. Hence, anxiety might have played a role in the changes in the perception of gap crossability.

Based on the findings of the present thesis, we would argue that an observer who is in a threatening environment will pick up information of the environment as well as information of his or her own body. The latter will deviate from ordinary feelings, sensations and so on, and the observer will behave accordingly (for illustrations, see Chapters 2-5). To single out an example from this thesis, a threatening environment affected the neuromuscular system (see Chapter 2),[1] and observers 'would be wise' to account for these effects when asked for their action capabilities in that environment. Thus, from the perspective of the mutuality of observer and environment—one of the central tenets of ecological psychology (Gibson, 1979)—it is most likely that information of the environment and the actor's emotional state will be picked up and thus affect the individual's perception of affordances and the performance of the action. For that reason, it is important to establish participants' action capabilities in the anxiety conditions applied. (It is perhaps important to note that Jiang and Mark [1994] measured each person's actual stepping capability by asking him or her to step as far forward as they could *on the floor*, hence in an emotionally neutral situation.)

The results of Chapters 4-5 underscored the idea that state variables such as anxiety and

[1] Note that very small changes in human motor coordination may lead to dramatic changes in end performance. For example, a small change in the timing of one muscle may completely deteriorate jumping performance (e.g., van Ingen Schenau, van Soest, Gabriëls, & Horstink, 1995; van Soest, 1992).

fatigue co-determine which affordances are being perceived and realized and emphasize the intricate relation between perception and action. Information about changes in the state of the actor is automatically incorporated in perceiving and realizing affordances. The results show that actors use current and up-to-date information about their particular state, and changes therein, in perceiving and realizing affordances. Thus, it appeared that observers actually use this available ‘state-scaled’ information in making judgements about maximal reaching height (see Chapters 4-5). In this respect, the effects of (temporal) changes in one’s state greatly resemble the effects of, for example, (temporal) changes in eye-height (Mark, 1987), running speed (Oudejans, Michaels, Bakker, & Dolné, 1996; Oudejans, Michaels, van Dort, & Frissen, 1996), or ground surface on the perception of affordances (Pepping & Li, 2000). For instance, Mark (1987) showed that observers use the available eye-height-scaled information as a basis for their judgements about whether the heights of various surfaces afforded sitting or climbing on. Mark then increased the observers’ eye-height by having them wear 10-cm blocks under their feet, which increased both the observers’ eye-height and the maximum height of a surface on which observers could sit. The new maximum sitting height is a smaller fraction of the new eye-height (both are increased by the same amount, i.e., 10 cm), therefore observers should underestimate their own actual sitting capabilities when wearing the blocks. This prediction follows from the use of available eye-height-scaled information in making judgements about whether a surface affords sitting on. It appeared that only in the first trial observers underestimated their own new actual sitting capabilities, and that they quickly discovered the altered sitting capabilities.[2] Similar effects were found in the study of Pepping and Li (2000). They demonstrated that depending on the elasticity properties of the ground surface participants judged their reach-with-jump action differently: The perceptual adaptation appeared to be in the same direction as the actual change of reaching ability.

The flexible manner in which changes in the (psychological) state of the actor are incorporated in perception and action fits well with the quick adaptations to changes in eye-height, running speed, and ground surface discussed in the previous paragraph, and underscores the importance of on-line information about environmental, task, and organismic constraints for perception and action. It is widely acknowledged that affordances are intimately linked to those constraints on action (cf. Newell, 1986), resulting in a dynamical animal-environment fit. People constantly adapt their actions to changes in the environment, the task and the human action system itself (Bingham, 1988). Regarding the human action

[2] In a follow-up study, Mark, Balliett, Craver, Douglas, and Fox (1990) demonstrated that information-gathering activities (e.g., locomoting between trials, rotating the head while making the judgements) are crucial for revealing information about their own new actual sitting capabilities. This is in keeping with results of Oudejans and colleagues who demonstrated that being in motion improves the perception of action possibilities, such as the perception of catchableness of fly balls (Oudejans, Michaels, et al., 1996), or the perception of the crossableness of a busy road (Oudejans, Michaels, van Dort, et al., 1996).

system, research has predominantly focused on geometric measures (e.g., arm length, leg length; see, e.g., Carello, Grosofsky, Reichel, Solomon, & Turvey, 1989; Mark, 1987; Mark et al., 1997; Warren, 1984, 1988), biomechanical constraints such as strength, limb mobility, and joint flexibility (e.g., Konczak, Meeuwsen, & Cress, 1992), and kinetic measures (e.g., Pepping & Li, 2000). The results of the present thesis support the notion that the boundaries for action are also defined by the observers' state. State variables change the actors' action capabilities, and in keeping with this also the perception of affordances changes. Moreover, the finding that brief hands-on experience with the task also led to a quick recalibration of the perception of maximal reaching height, is consistent with the idea that perception of affordances smoothly adapts on the basis of on-line information about the constraints of the situation encountered.

Thus, the results suggest that throughout the movement, emotional state feedback offers important guidance in the ongoing control of actions by revealing changes in one's action possibilities as it progresses. Rather than undermining some of the principles of ecological psychology, this thesis demonstrates that emotional state variables and the accompanying changes in perception and action are fully in accordance with those principles.

Modelling anxiety-performance relationships

A profound question in anxiety research is what the precise impact of anxiety is on end performance (e.g., Jones, 1995a). Evidently, insight into effects of anxiety on end performance is relevant, especially in sport and other domains in which performers often act under pressure such as dance, music making, installing law and order and fire fighting. Do the results of the present thesis tell us something about the relation between anxiety and end performance? To answer this question it is useful to revisit the discussion on anxiety-performance models of Chapter 1.

Part of the performance variance following anxiety stems from the multidimensionality of anxiety. In this regard, the development of the 'multidimensional anxiety-based approaches'—that is, multidimensional anxiety theory (Martens, Vealey, & Burton, 1990) and the cusp catastrophe model (Hardy, 1990, 1996)—was a major step forward in understanding the anxiety-performance relationship. Recall that multidimensional anxiety theory predicts that cognitive and somatic anxiety will differentially influence end performance, predicting a negative linear relationship between cognitive anxiety and performance, and an inverted-U relationship between somatic anxiety and end performance.[3] Hardy's (1990, 1996) cusp catastrophe model also uses a multidimensional conceptualisation of anxiety to examine and

[3] Although multidimensional anxiety theory has been tested in the sport context, with only limited or partial support (Gould, Greenleaf, & Krane, 2002), a body of literature has supported the utility of distinguishing between cognitive and somatic anxiety components in anxiety research, and "there is potentially a great deal to be learned from their interplay." (Jones, 1995a, p. 456)

predict *interactive* effects of cognitive anxiety and physiological arousal upon performance. Cognitive anxiety would have a positive relationship with performance when physiological arousal is low, but a negative relationship when physiological arousal is high. When cognitive anxiety is low (as in most laboratory situations), the model predicts that physiological arousal has an inverted-U shaped relationship with performance. In contrast, when cognitive anxiety is high, increased levels of physiological anxiety lead to a 'catastrophic' drop in performance.[4]

Thus, the adoption of the multidimensional anxiety notion helps to account for some of the mixed and inconclusive findings regarding the effects of anxiety on end performance. However, these approaches are limited in that they seem less suitable to explain why the same anxiety manipulation may lead to different effects on performance as found in the current thesis. For example, in most of the reported experiments anxiety led to a longer climbing time. However, in Experiment 1 of Chapter 2 the climbing time in which participants had to execute the task was preset, and participants were able to meet the set criterion time despite several effects of anxiety (e.g., more muscle fatigue). Furthermore, when given the opportunity participants took advantage of the abundance of holds in the anxiety conditions in Experiment 2 of Chapter 4, while in the other experiments participants managed to climb the high horizontal route using significantly less holds. Apparently, participants were able to override several of the effects of anxiety with additional effort in order to meet the requirements of the specific situation. In all cases, the manipulation of anxiety was the same, yet different effects on performance seemed to have occurred, which are difficult to explain with the multidimensional-anxiety based approaches.

In applying an ecological approach to explaining the different effects of the same anxiety manipulation on human motor performance, Mark's (Mark, 1995; Mark et al., 1997) distinction between *absolute* and *preferred* critical boundaries is relevant. Mark et al.'s (1997) point of departure was that the absolute critical boundary for a particular mode of action does not delimit the conditions under which that action will be performed when multiple action modes can be used to realize the intended goal. They argued that even when the absolute critical boundary for a particular action mode (i.e., for reaching only using arm extension) has not been exceeded, that mode might not be chosen because another mode may be more comfortable, and require less effort to perform (i.e., reaching and using the upper torso to lean forward). Mark et al. therefore proposed, and demonstrated, that, rather than the absolute

[4] Various studies offer support for the predictions of the cusp catastrophe model (e.g., Edwards & Hardy, 1996; Edwards, Kingston, Hardy, & Gould, 2002; Hardy, 1996; Hardy, Woodman, & Carrington, 2004; Woodman, Albinson, & Hardy, 1997). However, it has also been argued that the cusp catastrophe model, although promising, "lacks the sound framework necessary to examine the effects of multidimensional anxiety and physiological arousal on motor performance" (Cohen, Pargman, & Tenenbaum, 2003, p. 155).

critical boundary, the preferred critical boundary—reflecting the relative comfort of available modes of action—delimits the boundaries for various actions. As another example, it is known that gait transitions in horses, for instance, from walking to trotting to galloping, are for a major part determined by energetic costs of the gait patterns in question (Hoyt & Taylor, 1981). Organismic constraints such as anxiety seem to be integrated with constraints related to the actor's comfort and biodynamic costs. Consequently, if an abundance of holds is available (Experiment 2, Chapter 4), heightened anxiety will lead to the use of more holds to climb a route as participants preferred to select another, more comfortable, mode of action to fulfil the task. If participants are forced to climb the traverse within a preset time (Experiment 1, Chapter 2), all participants will probably be able to meet this requirement, but only at the cost of more energy expenditure. Hence, it seems important to consider the factor 'required effort' in modelling anxiety-performance relationships.

The importance of required effort was recognized by Eysenck and Calvo (1992). They started from the observation that increases in anxiety do not automatically have to result in performance decrements, and from the theoretical position that processing efficiency—that is, task performance divided by effort—influences the quality of task performance (performance effectiveness). In their view, anxiety typically impairs processing efficiency, but not necessarily task performance. Thus, the processing efficiency theory explains how individual differences in trait anxiety interact with state anxiety and attentional mechanisms in affecting performance. It predicts that anxious individuals will invest more effort in the task at hand if they feel they have a reasonable chance of success (Woodman & Hardy, 2003). As such, the theory might provide an answer to a growing body of literature suggesting that anxiety has both facilitative and debilitative functions (e.g., Jones, 1995; Jones & Uphill, 2004; Swain & Jones, 1996). Support for the predictions of the processing efficiency theory has been provided in several recent empirical investigations (e.g., Murray & Janelle, 2003; Smit, Bellamy, Collins, & Newell, 2001; Williams, Vickers, & Rodrigues, 2002), confirming the idea that invested effort is an important factor in anxiety-performance relationships.

The gist of the preceding discussion is that unravelling the precise details of the anxiety-performance relationship remains a major challenge to future researchers in this area. The complex phenomena involved often cannot be explained in simple terms using general and simple models (Jones, 1995a).[5] Moreover, the recent literature on choking under pressure in

[5] In the current thesis a nomothetic (group-oriented) perspective was used, ignoring, by definition, the large inter-individual variability in anxiety responses. Hence, an alternative approach would be to develop individualized anxiety and performance measures as a means to establish individualized optimal anxiety performance relationships, and thus giving practitioners tools to help athletes in enhancing their performance. Hanin's 'individual zone of optimal functioning (IZOF) model (Hanin, 1980, 1989, 2000) provides such an individualized approach. Hanin suggested that through retrospective and systematic multiple observations of an athlete's anxiety and performance levels, a

sports reveals that several additional factors that have not been addressed in this thesis also play a role in the anxiety-performance relationship. Whether athletes choke or not, for instance, is dependent on the kind of task (e.g., Beilock & Carr, 2001; Beilock, Kulp, Holt, & Carr, 2004), task complexity (e.g., Beilock & Carr, 2001; Masters, 1992), personality characteristics (e.g., Baumeister, 1984; Masters, 1992; Wang, Marchant, Morris, & Gibbs, 2004), whether a given task was learned implicitly or explicitly (e.g., Law, Masters, Bray, Eves, & Bardswell, 2003; Masters, 1992; Mullen & Hardy, 2000), and expertise level (e.g., Beilock, Carr, MacMahon, & Starkes, 2002; Wulf, McNevin, Fuchs, Ritter, & Toole, 2000). In this context, the recent work of Reeves (2005) is worth mentioning. She investigated when and where choking under pressure occurs while taking into account a large number of these factors—that is, attentional direction (external and internal), attentional relevance (relevant and non-relevant), task difficulty (simple and complex), and skill-level (expert, sub-elite, and novice). Among other things, Reeves found "that participants focusing internally on non-relevant aspects of performance (i.e., one's thoughts, or the arm in soccer) choke under pressure, regardless of expertise-level or task difficulty" (p. x). Getting used to such an internal focus by practising under conditions with increased internal attention has been demonstrated to prevent choking in beginners (Beilock & Carr, 2001; Lewis & Linder, 1997) and experts alike (Oudejans & Pijpers, 2005).

To conclude, as was amply illustrated in the present thesis, anxiety affects a plethora of variables at different levels, which makes it difficult, if not impossible, to come up with an all-encompassing theory for the relationship between anxiety and performance. Nevertheless, systematic investigation of these changes and underlying processes might help explain anxiety effects on performance and provide good starting points for building such a theory and for developing stress management techniques. In addition, it may help in developing a theory of perception and action incorporating not only the more physical, but also the more psychological constraints.

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zone of optimal functioning (ZOF) can be identified. The model predicts that individual successful performance occurs when an athlete's anxiety level is near or within the previously established optimal zones. For more information about the validity and practical utility of the individualized zones of optimal functioning model, see Jokela and Hanin (1999).

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Samenvatting
(Summary in Dutch)

De invloed van angst op perceptueel-motorisch gedrag

Het centrale thema van dit proefschrift is de invloed van toestandsvariabelen, in het bijzonder toestandsangst,[1] op het perceptueel-motorische gedrag. Een taak die zich goed leent voor de bestudering van dit onderwerp is het klimmen op een indoorklimwand. De deelnemers klommen zowel laag op de klimwand, de *angstneutrale-conditie* genoemd, als hoog op de klimwand, de *angstconditie* genoemd. In alle experimenten die in dit proefschrift worden gerapporteerd, bleek deze angstmanipulatie effectief te zijn. In de regel moesten de deelnemers een horizontale route klimmen die door middel van grepen was uitgezet op de klimwand. De in het proefschrift beschreven experimenten beogen op de eerste plaats meer inzicht te verschaffen in de processen die ten grondslag liggen aan de veranderingen in motorisch gedrag onder invloed van toestandsangst. Daarnaast wordt beoogd de invloed van toestandsvariabelen op het waarnemen, selecteren en realiseren van handelingsmogelijkheden beter te doorgronden. Het accent ligt daarbij op de variabele angst en, in mindere mate, op de variabele vermoeidheid.

In *Hoofdstuk 1* wordt het theoretische kader van dit proefschrift, de ecologische psychologie, kort geschetst. Binnen deze benadering wordt uitgegaan van de onlosmakelijke relatie tussen zowel persoon en omgeving, als tussen waarnemen en bewegen, waardoor uiteindelijk een beschrijving van de omgeving resulteert in termen van op de persoon toegesneden handelingsmogelijkheden, zogenoemde *affordances* (Gibson, 1979). Hoewel het begrip affordance behoort tot de fundamenten van de ecologische psychologie, woedt er een levendige discussie over de precieze betekenis van dit begrip. De verschillende opvattingen over het begrip affordances staan echter vragen over factoren die een rol spelen bij het waarnemen en realiseren van handelingsmogelijkheden niet in de weg. Onderzoek naar die vragen kan plaatsvinden aan de hand van Newell’s (1986) driedeling van *constraints*. Constraints zijn ‘beperkende factoren’, ofwel factoren of eigenschappen die mogelijke handelingen inperken of begrenzen. Newell onderscheidde omgevings-constraints (bijvoorbeeld zwaartekracht, omgevingstemperatuur), taak-constraints (zoals taakinstructies en spelregels in de sport) en organisme-constraints (bijvoorbeeld sprongkracht, maximale loopsnelheid, maar ook factoren als nervositeit en vermoeidheid). De twee laatstgenoemde voorbeelden zijn psychologische toestandsvariabelen. Aan dat type variabelen is binnen de ecologische psychologie tot nu toe weinig aandacht besteed bij het bestuderen van het waarnemen en realiseren van handelingsmogelijkheden, hoewel er diverse redenen zijn om te veronderstellen dat die variabelen een rol spelen (Stoffregen, 2003).

[1] De term anxiety’ wordt in dit proefschrift vertaald met ‘toestandsangst‘ en wordt opgevat als een momentane emotionele reactie ter onderscheid van angst als dispositie of persoonlijkheidstrek (zie ook Hoofdstuk 1).

De keuze voor de ecologische psychologie als theoretisch kader voor het bestuderen van de relatie tussen toestandsangst en perceptueel-motorisch gedrag wordt gemotiveerd op basis van een kritische samenvatting van de uitgebreide literatuur over de angst-prestatie-relatie in de sportpsychologie en de daarbinnen vigerende theoretische modellen en methoden van onderzoek. De conclusie van deze uiteenzetting is dat het gebrek aan eenduidigheid in de resultaten van het onderzoek naar de invloed van toestandsangst op het motorisch gedrag in belangrijke mate kan worden toegeschreven aan het overwegend productgeoriënteerde karakter van de gehanteerde theoretische modellen. De verwachting is dat een procesgeoriënteerde benadering een betekenisvolle(re) bijdrage kan leveren aan het verhelderen van het verband tussen toestandsangst en perceptueel-motorisch gedrag, en dat het theoretische kader van de ecologische psychologie bij uitstek geschikt is om een dergelijke benadering te ontwikkelen.

In de Hoofdstukken 2 en 3 wordt vanuit een procesgeoriënteerde invalshoek het verband tussen toestandsangst en bewegingsgedrag bestudeerd. In *Hoofdstuk 2* worden de manifestaties van toestandsangst op drie niveaus onderzocht, te weten het niveau van subjectieve ervaring, het fysiologische niveau en het gedragsniveau. In Experiment 1 werd de deelnemers gevraagd een klimtaak binnen een vastgestelde tijd uit te voeren, zowel in een angstneutrale conditie als in een angstconditie. Vergeleken met de angstneutrale conditie ervoeren de deelnemers in de angstconditie meer toestandsangst, waren de gemiddelde hartslag en melkzuurconcentratie in het bloed van de deelnemers hoger en was hun spiervermoeidheid groter. Het tweede experiment had tot doel te onderzoeken of de subjectieve en fysiologische veranderingen bij toestandsangst gevolgen hebben voor de bewegingsuitvoering. Het idee dat hieraan ten grondslag ligt, is dat toestandsangst een (tijdelijke) terugval teweegbrengt in de bewegingsuitvoering naar een uitvoering die kenmerkend is voor een eerdere fase in het motorische leerproces. De taak wordt als het ware op een lager vaardigheidsniveau uitgevoerd met de bij dat niveau van uitvoering behorende bewegingskarakteristieken zoals langzame, onregelmatige, schokkerigere en houterige bewegingen. Om het bewegingsgedrag in de twee angstcondities in kaart te brengen, werd gebruikgemaakt van de zogenoemde ‘geometric index of entropy’, in het vervolg kortweg ‘entropie’ genoemd. Cordier e.a. (1993, 1994) ontwikkelden deze entropiemaat om de moeilijkheidsgraad van klimroutes te kwantificeren: hoe hoger de entropie, des te moeilijker de route. De auteurs beargumenteerden ook dat er een sterke correlatie is tussen de vaardigheid van een klimmer en de mate van entropie: hoe vaardiger de klimmer, hoe vloeiender hij of zij klimt en des te lager de entropie. Uitgaande van het idee dat in de angstconditie deelnemers terugvallen naar een lager vaardigheidsniveau, werd in Experiment 2 verwacht dat in die conditie de entropie stijgt, evenals de tijd die het kost om de klimroute te voltooien. Beide verwachtingen kwamen uit en duiden erop dat de bewegingsuitvoering onder invloed van toestandsangst gelijkenis gaat vertonen met die van een ‘beginner’. De bevindingen zijn in overeenstemming met de hypothese van de bewuste informatieverwerking van Masters (1992). Volgens deze hypothese kan toestandsangst een bewuste bewegingssturing oproepen die vervolgens kan leiden tot een tijdelijke terugval naar een lager vaardigheidsniveau of naar een uitvoering die kenmerkend is voor een eerdere leerfase. De bewuste processen interfereren met de in de regel automatisch verlopende taakuitvoering waardoor de taakprestatie verslechtert.

Hoofdstuk 3 borduurt voort op Hoofdstuk 2 en rapporteert twee experimenten waarin de op basis van Masters’ (1992) hypothese verwachte effecten van toestandsangst op de bewegingsuitvoering werden onderzocht. Verwacht werd dat angst zou leiden tot een verhoogd zelfbewustzijn waardoor de bewegingssturing meer bewust en serieel zou worden, resulterend in langzamere bewegingen van greep naar greep en een langere voorbereidingstijd (dat wil zeggen, langer contact met de grepen). In Experiment 1 werd de deelnemers gevraagd een klimtaak uit te voeren in beide angstcondities waarbij geen tijdsbeperkingen werden opgelegd. Evenals in Hoofdstuk 2 bleek dat de klimtijd in de angstconditie langer was dan in de angstneutrale conditie, hetgeen onder meer te maken had met een toename van het aantal explorerende handelingen. Die toename kon de langere klimtijd echter niet volledig verklaren, reden waarom in Experiment 2 ook de temporele aspecten van de bewegingen werden geanalyseerd. Temporele veranderingen kunnen duiden op een door toestandsangst teweeggebrachte bewuste bewegingssturing zoals voorspeld door Masters. Uit de resultaten bleek dat bij hogere toestandsangst-scores de klimtijd langer was, meer explorerende bewegingen werden gemaakt, de contacttijd van handen en voeten met de grepen langer was en, ten slotte, bewegingen van greep naar greep trager waren. Deze bevindingen zijn, net als die in Hoofdstuk 2 (Experiment 2), in overeenstemming met Masters’ hypothese.

De in de Hoofdstukken 2 en 3 toegepaste en gepropageerde procesgeoriënteerde benadering van de relatie tussen angst en motorische prestatie leidde tot de constatering dat er vooralsnog weinig aandacht is besteed aan de rol van perceptuele processen binnen het onderzoek naar angst en motorische prestatie. In het licht van de nauwe verbondenheid tussen waarnemen en bewegen, zoals ook sterk benadrukt in de ecologische psychologie, ligt de bestudering van de invloed van angst op perceptuele processen voor de hand. In *Hoofdstuk 4* worden drie experimenten beschreven waarin de rol van toestandsangst bij het waarnemen en realiseren van handelingsmogelijkheden werd onderzocht. In Experiment 1 werd deelnemers gevraagd om, staande in de klimwand, schattingen te maken van hun maximale reikhoogte. Toestandsangst werd gemanipuleerd door de schattingstaak laag en hoger op de klimwand te laten uitvoeren. Na de schattingen werd in beide condities de maximale reikhoogte bepaald (in het vervolg de ‘werkelijke’ reikhoogte genoemd). Toestandsangst bleek te leiden tot een reductie van zowel geschatte als werkelijke reikhoogte.

In Experiment 2 werd onderzocht of naast de veranderingen in de geschatte en de werkelijke maximale reikhoogte ook veranderingen optraden in het realiseren van handelingsmogelijkheden. De deelnemers werd (veel) keuzemogelijkheden geboden bij het klimmen van de route door een route uit te zetten die bestond uit een groot aantal grepen. De deelnemers klommen opnieuw in beide angstcondities. Net als in Experiment 1 van Hoofdstuk 3, bleek dat de deelnemers in de angstconditie meer explorerende bewegingen maakten dan in de angstneutrale conditie. Tevens bleek dat de proefpersonen in de angstconditie meer grepen gebruikten om de route te klimmen dan in de angstneutrale conditie.

In Experiment 3 werd de hypothese getoetst dat naast de veranderingen in waargenomen en werkelijke reikhoogte als gevolg van toestandsangst, ook veranderingen in aandacht plaatsvinden. Aandachtsverschuivingen kunnen worden beschouwd als onderliggend mechanisme van veranderingen in het waarnemen en realiseren van handelingsmogelijkheden door toestandsangst. De deelnemers aan Experiment 3 voerden behalve de klimtaak ook een tweede taak uit. Terwijl de deelnemers klommen (opnieuw in de beide angstcondities) werden lichtjes geprojecteerd op de klimwand. De taak van de deelnemers was om telkens als zij een lichtje hadden waargenomen dit zo snel mogelijk verbaal aan te geven. Uit de resultaten bleek dat de deelnemers in de angstconditie minder lichtjes detecteerden dan in de angstneutrale conditie, hetgeen opgevat werd als indicatie van versmalde aandacht. De conclusie van de studie was dat de emotionele toestand van de waarnemer invloed heeft op het waarnemen en realiseren van handelingsmogelijkheden, in samenhang met veranderingen in aandacht en de werkelijke capaciteiten van de deelnemers.

Een nadeel van het manipuleren van een variabele zoals angst is dat de mogelijkheden om gecontroleerde gradaties in angst op te wekken beperkt zijn; ook heeft het uitlokken van extreme angst ethische beperkingen. Genoemde beperkingen gelden in mindere mate voor een variabele als vermoeidheid. Om die reden wordt in *Hoofdstuk 5* de invloed van vermoeidheid op het waarnemen en realiseren van handelingsmogelijkheden onderzocht teneinde na te gaan of de bevinding van Hoofdstuk 4 – angst speelt een rol bij het waarnemen en realiseren van handelingsmogelijkheden – gegeneraliseerd kan worden naar een andere toestandsvariabele, in dit geval, vermoeidheid. In Experiment 1 klommen de deelnemers een horizontale route laag op de klimwand. Het aantal keren dat de route moest worden geklommen varieerde om de vermoeidheid van de deelnemers te manipuleren. Verspreid over twee dagen klommen de deelnemers 4, 6, 8 of 10 trials (de volgorde werd aselect zonder teruglegging bepaald) waarbij 1 trial was gedefinieerd als het van rechts naar links klimmen van de route en vervolgens weer terugklimmen naar de uitgangspositie. Voorafgaand aan het klimmen en na iedere twee trials schatten de deelnemers hun maximale reikhoogte en gaven ze aan hoe vermoeid ze zich op dat moment voelden (RPE-scores, *ratings of perceived exertion,* Borg-schaal). Op een andere dag klommen de deelnemers opnieuw 10 trials, maar nu werd na iedere twee trials de werkelijke reikhoogte bepaald. Hogere vermoeidheidsscores gingen gepaard met lagere schattingen van de maximale reikhoogte; de werkelijke reikhoogte bleef echter constant. Opmerkelijk was dat de perceptuele veranderingen vooral optraden aan het begin van de taakuitvoering wanneer de deelnemers aangaven nauwelijks vermoeid te zijn. Wanneer de vermoeidheid toenam, had dat nauwelijks effect op de waargenomen (en werkelijke) reikhoogte.

Op basis van de resultaten van pilotstudy's werd verwacht dat de meeste deelnemers uitgeput zouden zijn na het klimmen van 10 trials. Dit bleek echter niet het geval te zijn voor een deel van de deelnemers aan Experiment 1. Daarom werd in Experiment 2 aan een andere groep deelnemers gevraagd tot uitputting te klimmen. Opnieuw werd gevonden dat vooral aan het begin van de taakuitvoering perceptuele veranderingen optraden. Wanneer de deelnemers aangaven zeer vermoeid tot uitgeput te zijn, liepen de perceptuele veranderingen in de pas met de werkelijke veranderingen in maximale reikhoogte. Op basis van de resultaten van Experimenten 1 en 2 (en in overeenstemming met de eindconclusie van Hoofdstuk 4) kan worden gesteld dat er een functioneel verband bestaat tussen waargenomen handelingsmogelijkheden en de werkelijke *capaciteiten* van de deelnemers en niet zo zeer een verband tussen de mate van vermoeidheid *an sich* en waargenomen handelingsmogelijkheden.

In de epiloog, *Hoofdstuk 6*, worden de belangrijkste resultaten van dit proefschrift samengevat en worden de implicaties ervan besproken voor het onderzoek naar de invloed van toestandsangst op het perceptueel-motorische gedrag. Beargumenteerd wordt dat het waarnemen en realiseren van handelingsmogelijkheden geschiedt mede op basis van 'toestandsgeschaalde' informatie, dat wil zeggen, up-to-date informatie over de toestand (bijvoorbeeld mate van nervositeit of vermoeidheid) van de handelende persoon. De resultaten stroken met de uitgangspunten van de ecologische psychologie zoals besproken in Hoofdstuk 1.

Het belang van een procesgeoriënteerde benadering van de relatie tussen toestandsangst en motorische prestatie wordt (nogmaals) benadrukt omdat met zo'n benadering naar verwachting recht kan worden gedaan aan het grote aantal processen dat van invloed is op, en ten grondslag ligt aan, het effect van toestandsangst op de uiteindelijke prestatie. Geconcludeerd wordt dat er vooralsnog geen alomvattend angst-prestatie-model bestaat dat rekening houdt met het grote aantal relevante factoren. Systematisch onderzoek naar de onderliggende processen van de toestandsangst-prestatie-relatie biedt evenwel aanknopingspunten voor het ontwikkelen van een dergelijk model; bovendien biedt het mogelijkheden een theorie van waarnemen en bewegen te ontwikkelen waarin ook plaats is voor psychologische organisme-constraints.

Dankwoord
(Acknowledgements)

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The author…

Foto: Annemieke Slager

… and how to reduce anxiety